RUNWAY INDEPENDENT AIRCRAFT
EXTREMELY SHORT TAKEOFF AND LANDING

REGIONAL AIRLINER
THE MODEL 110

prepared for

Dr. John A. Zuk, Chief
Advanced Technology Tiltrotor Project Office
NASA/Ames Research Center
Moffett Federal Airfield, California 94035

by

David W. Hall. P.E., Project Director
NASA/Cal Poly Advanced Concepts Partnership
California Polytechnic State University
San Luis Obispo, California 93407

on

April 15, 2003

FINAL REPORT

TABLE OF CONTENTS

List of Figures

List of Tables

INTRODUCTION

Airports throughout the United States are plagued with growing congestion. With the increase in air traffic predicted in the next few years, congestion will worsen. The accepted solution of building larger airplanes to carry more travelers is no longer a viable option, as airports are unable to accommodate larger aircraft without expensive infrastructure changes. Past NASA research has pointed to the need for a new approach, which can economically and safely utilize smaller airports. To study this option further, NASA requested the California Polytechnic State University at San Luis Obispo (Cal Poly/SLO) to design a baseline aircraft to be used for system studies. The requirements put forth by NASA are summarized in Table 1. The design team was requested to create a demonstrator vehicle, which could be built without requiring enabling technology development. To this end, NASA requested that the tested and proven high-lift system of the Boeing C-17 *Globemaster III* be combined with the fuselage of the BAe-146. NASA also requested that Cal Poly determine the availability and usability of underutilized airports starting with California, then expanding if time and funds permitted to the U.S.

Table 1. The Design Requirements are Straightforward.

Takeoff distance	≤	2,000	ft
Landing distance	≤	2,000	ft
Payload		70 passengers	
Range	≥	1,000	n.mi.
Cruise speed	≥	300kts	
Cruise altitude	≥	25,000	ft
Additional requirements:	Economically feasible Fly descending/decelerating simultaneous non-interfering (SNI) approaches		

TECHNICAL DISCUSSION

Initial Sizing

To begin sizing the airplane, twelve comparable existing regional jets were examined. Their data were used to create a weight trend in order to arrive at a rough estimate of takeoff gross weight (TOGW). The resulting weight trend is shown in Figure 1. Empty weight in pounds was plotted versus TOGW. The relationship shown was used to converge to an approximate value of TOGW for the Model 110 and the given mission requirements.

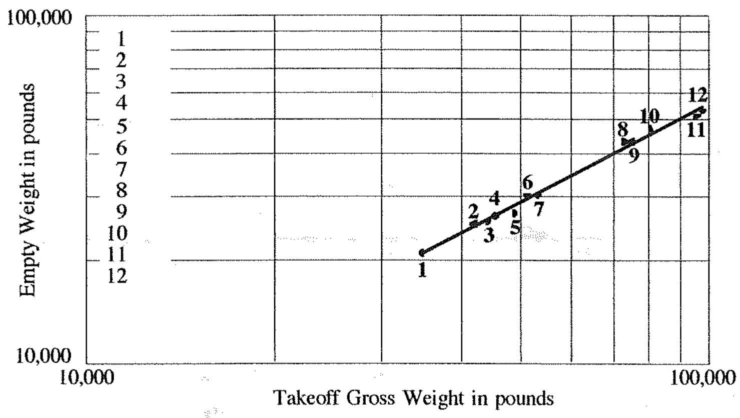


Figure 1. Historical Comparisons Yielded A Current Regional Jet Weight Trend.

To ensure the configuration met all the Table 1 mission requirements, a constraint plot was constructed. Several assumptions, driven by the requirements, were made in order to construct the plot. The number of engines was set at four in order to copy the C-17 lift system, which was a mission requirement. The landing deceleration was set at 0.8g, and engine takeoff and landing thrust lever settings of 75% were assumed based on industry noise reduction standards in airport traffic areas. Since the aircraft must attempt to meet all pertinent FARs, unless they are detrimental to the mission, the constraint plot took FAR Part 25 takeoff and landing requirements into consideration. In order to optimize the design, trade studies were conducted. Figure 2 presents the resulting constraint plot. Note that the initial design point inside the design space ensures that the Model 110 will meet all mission requirements. As can be seen in Figure 2, the range, landing stall speed and one-engine-inoperative (OEI) takeoff/landing requirements drove the design.

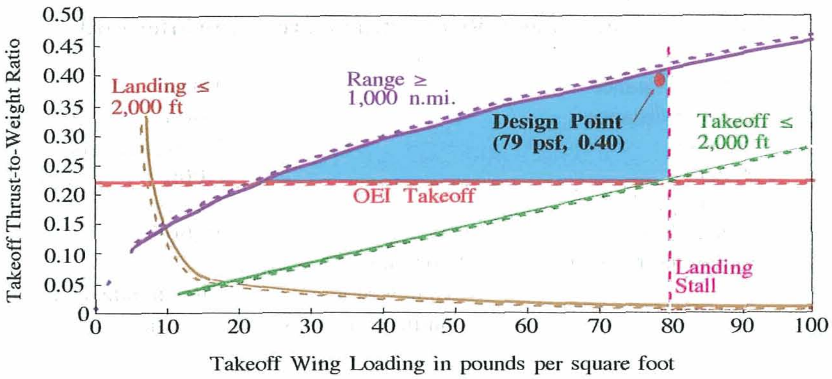


Figure 2. The Mission Requirements Can Be Used to Create a Constraint Plot.

One study of particular importance was the variation in takeoff wing loading and takeoff thrust-to-weight ratio as cruise speed and cruise altitude vary. Next, the trade study plot was overlaid on the constraint plot to ensure cruise conditions were met. As can be seen in Figure 3, the final design point is located in the design space, and meets the cruise speed and altitude stated in the mission requirements. The final design point uniquely determined the takeoff thrust-to-weight ratio, as well as TOGW. With these parameters and the data obtained about the C-17 wing, the configuration of the Model 110 could be defined.

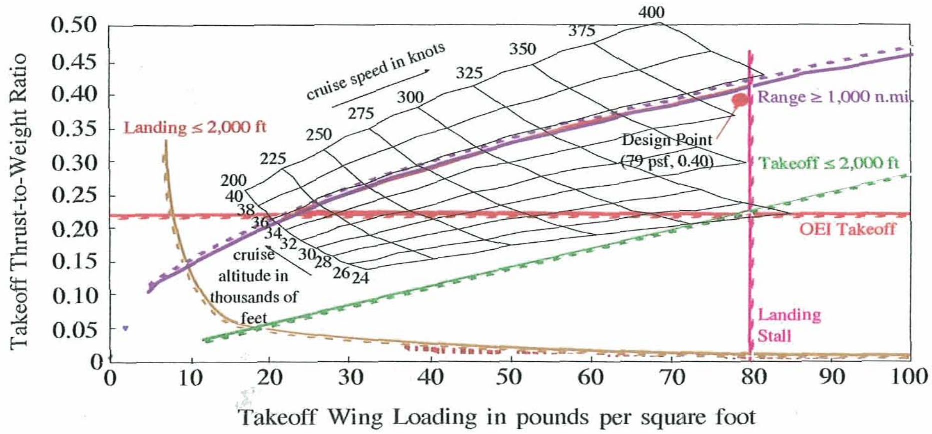


Figure 3. A Constraint Plot Overlays a Performance Trade Study.

Configuration

Selection of the design point allowed a large-scale layout to be created using a 27% scale Boeing C-17 wing and high lift system. Since mission requirements also stated that a BAe 146-100 fuselage should be used, information was obtained on the BAe 146-100 showing that it would be large enough to accommodate the required 70 passengers. For the baseline configuration, the CF34-3 engine was selected, as will be discussed later. Fuel tanks are located in the wings only, without the C-17's overhead fuel tank, which was eliminated in order to certify the Model 110 for commercial use. The final TOGW was 77,150 lb. Figure 4 and the foldout show the final baseline configuration.

Figure 4. The Baseline ESTOL Configuration Shows Off the Scaled C-17 Wing.

In order to provide flexibility to the low cost prototype approach, several alternative fuselages could be used. Four candidate fuselages, each able of carrying the required number of passengers, are the Antonov AN-74TK-300, the ATR 72-500, the Bombardier Dash-8 Q400 and the IPTN N-250 *Gutat Koco*. Photos of these four options are shown clockwise in Figure 5. Since these aircraft are also STOL vehicles, their empennages would most likely be large enough to meet current design requirements, although no detailed calculations were done for these configurations.

Figure 5. There Are Several Alternative Fuselages Which Could Be Used.

In addition to alternative fuselages, the Model 110 can also be outfitted with alternative engines. This provides additional flexibility to the baseline design. The engine selected would depend on the exact mission requirements, as well as concerns about weight, fuel efficiency, and range. Two alternatives were selected, the TF34-100A and the ALF502R-3A. They are shown along side the baseline CF34 in Figure 6.

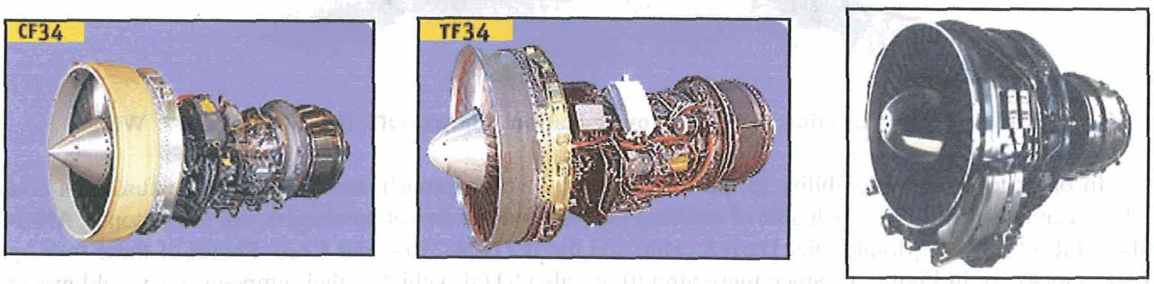


Figure 6. There Are Also Several Viable Engine Options.

The alternative engines impact many features of the aircraft. For detailed comparisons between the three options, see the Propulsion section.

The scaled-down C-17 wing used in the baseline configuration follows the same construction as the full-scale wing with six different airfoil sections blended over the semispan. More detailed information about the airfoil sections can be found in both the accompanying PowerPoint presentation and large-scale multi-view drawing. Knowing the geometry of the airfoils, the layout and volume of the fuel tanks were determined. The FARs dictate there can be no fuel over the cabin, and exclusion areas were placed over the engine pylons to accommodate their structural attachments. The final layout consists of three integral tanks, with a total fuel volume of 21,000 lb, and it is shown in Figure 7. Note that the outboard tank is not needed to meet the 1,000 n.mi. range requirement. Using the airplane without the outboard tank would result in a weight reduction and cost savings.

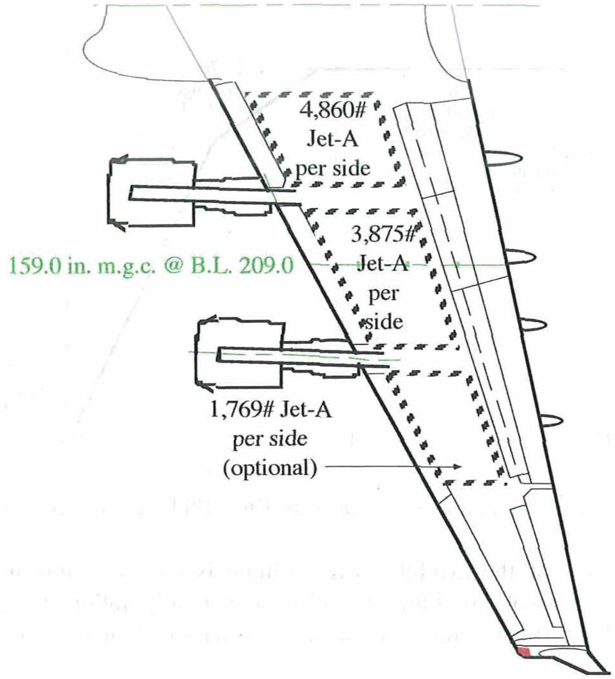


Figure 7. The Scaled Down C-17 Wing Contains Three Fuel Tanks.

A detailed weight breakdown, shown in Table 2, was determined next. As can be seen, the TOGW varies with choice of engine.

Table 2. The Three Alternative Engines Provide Slightly Different Aircraft Weights.

	CF34	TF34	ALF502
Structure (lb.)	25,788	25,788	25,788
Propulsion (lb.)	6,614	6,462	5,834
Equipment (lb.)	10,046	10,046	10,046
Total Empty Weight (lb.)	**42,449**	**42,297**	**41,669**
Fuel (lb.)	17,641	17,000	16,000
Payload (lb.)	17,060	17,060	17,060
Takeoff Gross Weight (lb.)	**77,150**	**76,356**	**74,728**

The fuel weights vary because each alternative is sized to the 1,000 n.mi. range requirement and each engine has a different fuel efficiency. The structural weight assumes the BAe-146-100 fuselage was used, and that the wing contains all three of the available fuel tanks.

By varying the payload and the fuel load, a payload/range diagram was constructed (Figure 8).

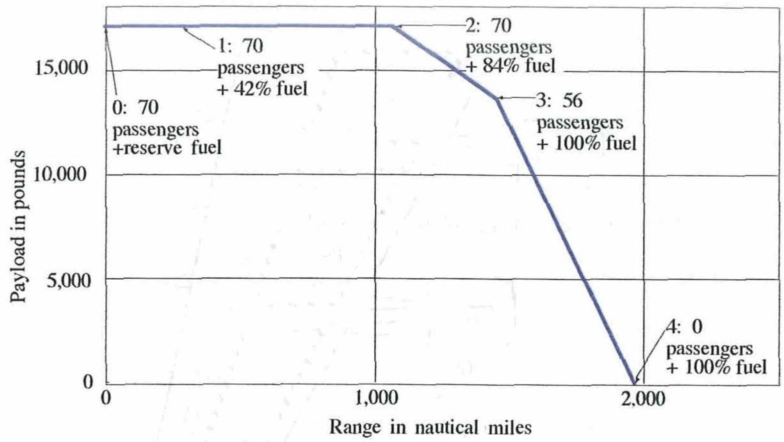


Figure 8. The Payload/Range Diagram for the Baseline ESTOL Meets the Mission Requirements.

For the CF34, only 84% of the available fuel volume is used and this has several implications. The outboard fuel tank can be made optional, providing extended range configurations to operators. This would cause a rise in TOGW, and, therefore, has not been studied in detail. The payload/range diagram in Figure 9 shows all three of the engine options.

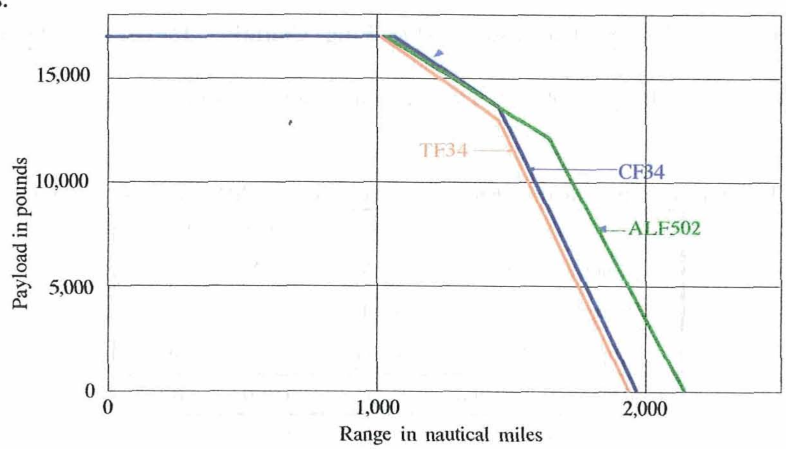


Figure 9. Payload/Range Diagram Show That All Engine Options Meet Mission Requirements.

Based on these plots and other basic calculations, it would appear the ALF502 provides the longest range; however, this does not take into account engine reliability or installed weight.

Structural Considerations

In adapting the C-17 wing to the BAe-146-100 fuselage, there were several structural issues which had to be addressed. Based on preliminary calculations, the empennage of the BAe-146-100 is sufficient to handle high lift trim (horizontal stabilizer) and engine out (vertical stabilizer) requirements. However, due to the large crosswind capability required for the ESTOL mission and the need for dynamic stability and control at low speeds, further study is warranted. Compared to the BAe-146-100's original wing, the 27% scale C-17 wing is both larger in area and heavier than the stock BAe-146 wing. The increase is shown in Table 3.

Table 3. The Stock BAe-146 Wing is Smaller than the Scaled C-17 Wing.

Item	Units	Model 110	BAe-146-100
Weight	pounds	5,413	4,995
Area	sq.ft.	1,030	832
Distance between spars @ centerline	ft	9.5	4.5

The additional wing weight is not a concern, since the structure of the later models of the BAe-146 was modified to support the heavier –300 wing. The larger dimensions of the wing did require some structural changes in the fuselage. In order to accommodate the larger Model 110 wing, two new frames will need to be added to the existing fuselage structure. In order to simplify the manufacturing process, the new frames would be constructed in the same method as frames number 13 and 19 of the current BAe-146-100 fuselage. Altering the fuselage in this way would not require any new manufacturing processes or machinery, thereby reducing cost. Finally, the structural capabilities of the Model 110 were analyzed. The V-n gust load diagram shown in Figure 11 was constructed.

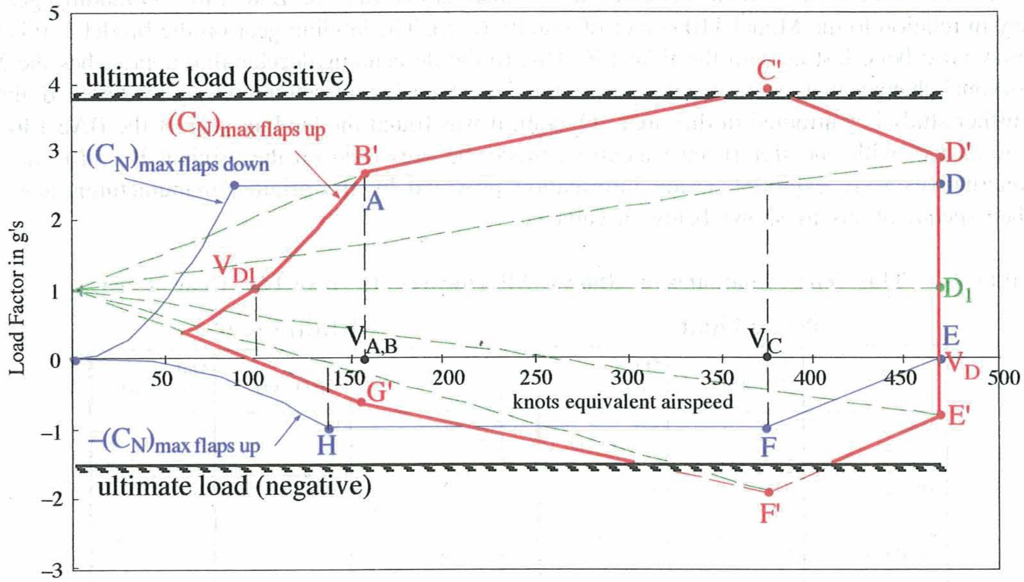


Figure 11. The Baseline Configuration Meets FAR 25 Structural Requirements as Shown in This V-n Diagram.

As shown, the ultimate loads cut off the gust maneuvering envelope at C' and F'. The various maneuvering speeds are shown in Table 4.

Table 4. Maneuvering Speeds for Baseline ESTOL are Lower than for Conventional Airliners.

Stall Speed	V_{D1}	99 knots
Design Maneuvering, Maximum Gust Intensity	$V_{A,B}$	157 knots
Cruise Speed	V_C	380 knots
Diving Speed	V_D	468 knots

The load diagram and table show that the Model 110 structure is strong enough to withstand any standard maneuver conducted by a regional airliner.

Landing Gear

The landing gear on the Model 110 is essentially the same as the current system in the BAe-146. The loads were calculated using the baseline TOGW, and are shown in Table 5.

Table 5. Landing Gear Loads and Weights (in pounds) are Typical for STOL Aircraft.

Main Gear Static Load	70,978
Nose Gear Static Load	6,172
Landing Gear Weight	2,791

The standard BAe-146 landing gear can carry these loads since it was designed to accommodate gross weights up to 94,000 pounds in growth versions. It was also shown that the BAe-146-100 landing gear is placed appropriately in relation to the Model 110 center-of-gravity (c.g.). The landing gear on the Model 110 is fitted with standard shock absorbers, just as with the BAe-146. Due to the descending/decelerating approaches the Model 110 will fly, additional changes may be necessary to accommodate extension/retraction under g-loading and high sink rate landings. Further study is warranted in this area. Overall, it was found the landing gear of the BAe-146 would not need to be modified, with one significant exception. Since the tires used on the original BAe-146 are no longer available, alternatives were explored. Using information provided by the original manufacturer, new tires were selected. Their specifications are shown below in Table 6.

Table 6. This Tire Comparison Shows Alternatives to BAe-146 Gear Exist.

Nose Gear

	New DR15840T	Old DR15856T
Type	VII	VII
Tire Size	24x7.7	24x7.7
Ply Rating	14	14
Speed Rating (mph)	190	225
Max Load (lbs)	8,200	8,200
Typical Weight (lbs)	29.4	27.4

Main Gear

	New DR11739T	Old DR11748T
Type	VII	VII
Tire Size	39x13	39x13
Ply Rating	18	24
Speed Rating (mph)	190	210
Max Load (lbs)	19,400	27,400
Typical Weight (lbs)	89.30	110.00

Since the landing gear are conveniently located in the fuselage, there is no modification necessary to the original doors, fairings, or locks. There is also no need to alter systems such as steering, emergency systems, kinematics, and cockpit requirements.

Propulsion

As requested in the RFP, the baseline ESTOL configuration uses the same high lift system as the C-17, namely externally blown flaps, in order to conform to the short takeoff and landing scenarios. A general picture of an externally blown flap system is shown in Figure 12.

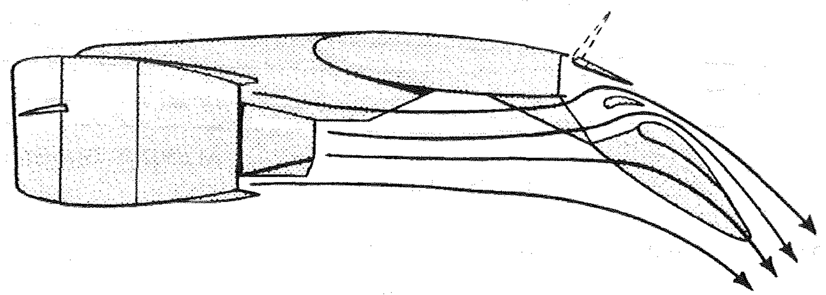


Figure 12. The C-17 Externally Blown Flap System is Scaled Down for the Model 110.

However, simply scaling the system down is not the most effective method of adapting it. Therefore, several options were explored. To select an engine, the minimum required installed thrust was determined using the TOGW and a four-engine arrangement to blow a similar percentage of the wing to the C-17. Engine alternatives were selected based on their individual performance characteristics, which are detailed in Table 7.

Table 7. Engine Option Characteristics are Similar.

Item	Units	CF34-3	TF34-100A	ALF502R-3A
Sea level uninstalled thrust	pounds	9,270	8,100	6,570
Sea level installed thrust	pounds	8,288	7,200	5,800
Cruise specific fuel consumption	lb/lb/hr	0.682	0.700	0.640
Bypass ratio		6.2	6.2	5.6
Dry weight	pounds	1,478	1,440	1,283
Length	inches	103	100	56.8

Three engine options were selected. The CF34 is used on the baseline ESTOL configuration, with the TF34 and ALF502 being alternatives. It is interesting to note that the ALF502 was the engine originally used on the BAe-146. Mission performance was analyzed for each of the three engine options. As can be seen in Figure 13, the CF34 is far more powerful than any of the other engine options at 100% thrust lever setting, whereas the ALF502 produces the least thrust. Use of the CF34, then, allows for considerable growth in TOGW or shorter takeoff and landing distances as well as being able to throttle back for the baseline mission to reduce airport traffic area noise.

After analyzing the performance of the engines at 100% thrust lever setting, the setting was lowered to 75% which would be the standard setting to minimize airport area noise. The same general trend in thrust available is seen for this scenario, shown by the dashed lines in Figure 13.

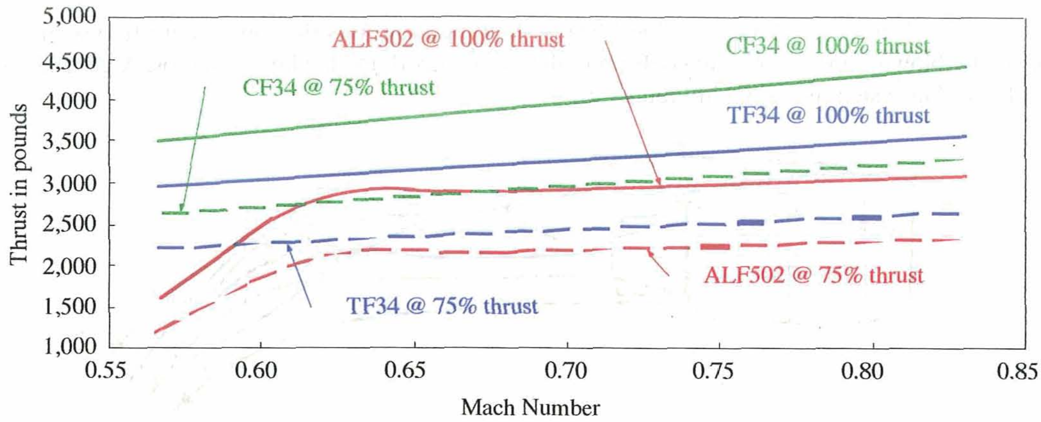


Figure 13. Engine Performance at 35,000 ft is Sufficient to Meet Mission Requirements.

The thrust specific fuel consumption (sfc) performance of each engine was also analyzed at 75% and 100% settings. The TF34's sfc at 75% thrust is the highest of any of the engine options. This can be seen in Figure 14. Since the Model 110 will be cruising at that thrust lever setting, the TF34 is the least efficient engine option at cruise. The baseline engine (CF34) falls in the center of the sfc range.

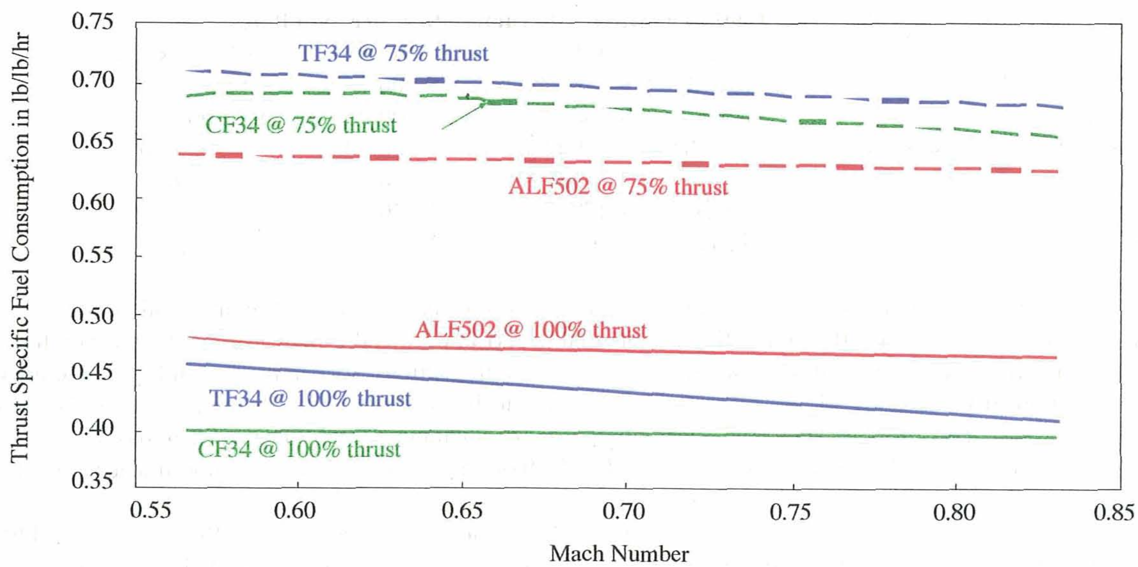


Figure 14. Engine Specific Fuel Consumption at 35,000 Feet Provides Low Cruise Fuel Burn.

Since the lift system works by externally blowing the flaps, high-temperature engine exhaust will be coming into contact with the flap structure. The temperature of the exhaust will be higher than the melting temperature of aluminum, the material generally used in flap construction. Therefore, the flaps must be made from titanium, which causes an increase in cost, as well as weight. Both are undesirable; therefore, additional studies should be done to justify this expense.

Nozzle and Nacelle Design

In order to optimize the blowing capability of the nacelle, the Model 110 will be fitted with tailored nozzles. Several designs were studied. The optimum design was a convergent nozzle with variable area, which would allow maximum blowing during takeoff and landing without impacting cruise performance. A scrap view of this design is shown in Figure 15, in takeoff/landing configuration.

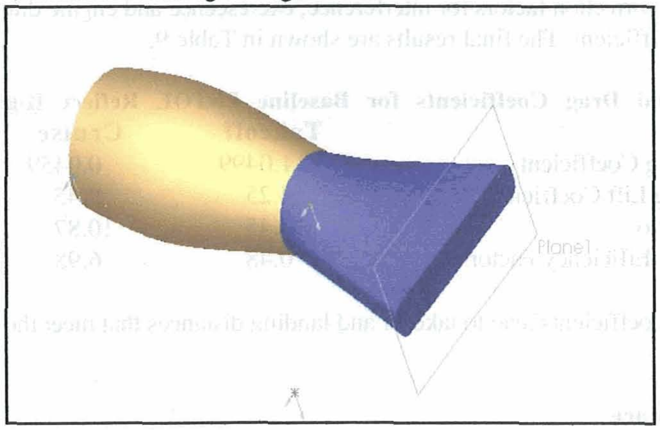


Figure 15. A Variable Area Nozzle May Improve Takeoff and Landing Performance.

However, this system is technically complex and would be difficult to manufacture and maintain. Other influences on the design are engine core exhaust temperature, as well as drag produced. Further studies are required to optimize the design, as well as determine the feasibility of a variable area system.

The nacelle design optimizes inlet area, provides thrust reversal, and minimizes drag. Preliminary dimensions are shown in Table 8.

Table 8. Nacelle Dimensions are Determined by Engine Choice.

Item	Units	CF34	TF34	ALF502
Diameter	in.	47.26	44.60	38.93
Inlet Area	sq.in.	1,227.93	1,093.60	833.21

Accessibility for maintenance was also considered. Three nacelle options exist, depending on the engine selected. The nacelle for the ALF502 is much smaller than the nacelle for the two other engine options, which allows for different placement as well as a savings in weight. Since the thrust reversal system depends greatly on the nozzle and nacelle designs, no final design will be offered at this time. Preliminary calculations show that it will include a cascade reversal system, which may include core flow.

Initial spanwise engine placement was arrived at by scaling down the C-17 positions. However, this caused structural and noise concerns. Also, the third engine (ALF502) option is much smaller than the other two, possibly allowing for a completely different placement compared to the CF34 and TF34. These are all areas that require further study before final placement decisions are made.

Performance

Drag and Lift Performance

The drag and lift coefficients were calculated for the Model 110 using methods in Cummings "Aerodynamic Drag". Compressibility and correction factors for interference, excrescence and engine drag were added, which resulted in the total parasite drag coefficient. The final results are shown in Table 9.

Table 9. Lift and Drag Coefficients for Baseline ESTOL Reflect High Lift Generation.

Item	Takeoff	Cruise	Landing
Total Drag Coefficient	1.0499	0.0459	1.2703
Operating Lift Coefficient	4.25	0.45	4.68
Glide Ratio	4.45	10.87	4.05
Transport Efficiency Factor	0.48	6.98	0.37

The operating lift coefficients lead to takeoff and landing distances that meet the RFP requirements.

Engine/Cruise Performance

The CF34 baseline engine, gives the thrust available versus thrust required curve shown in Figure 16 at sea level.

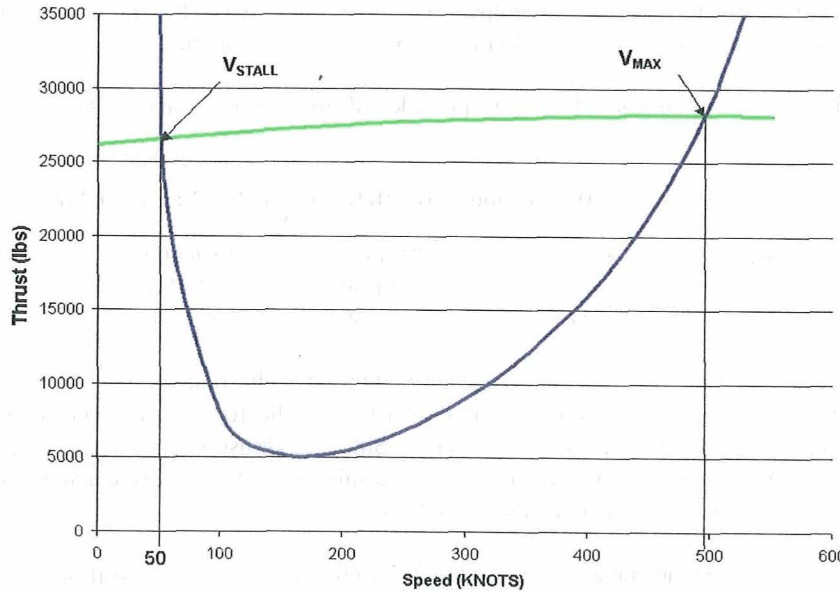


Figure 16. Thrust Available versus Thrust Required at Sea Level Shows Considerable Excess Thrust.

The Model 110 will not have problems in sea level takeoff scenarios, as the stall and maximum speeds are well within acceptable ranges. Since the Model 110 might be required to take off at a higher field elevation than sea level, the thrust available versus thrust required curves were also plotted for 5,000ft. The results are shown in Figure 17.

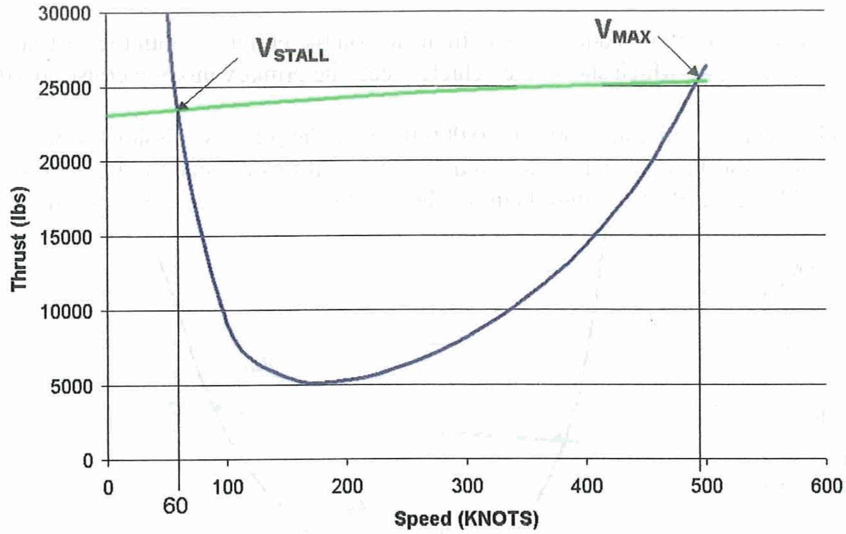


Figure 17. Thrust Available versus Thrust Required at 5000 Feet Shows the Potential for Good Climb Performance.

Once again, the stall and maximum level speeds do not cause a concern and the Model will still meet primary mission takeoff and landing requirements at 5,000 ft above sea level.

At the Model 110 cruise altitude of 25,000 ft, the CF34 baseline engines produce the thrust available versus thrust required curves shown in Figure 18.

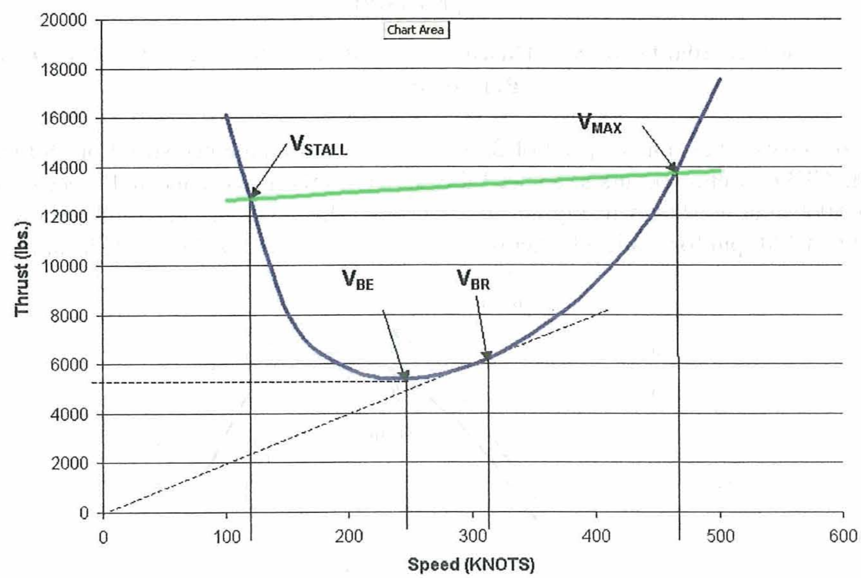


Figure 18. Thrust Available versus Thrust Required at 25000 Feet Exceed Mission Requirements.

The thrust lever setting is assumed to be 75%. Indicated on the graph are both the best range speed (320 kts) and best endurance speed (250 kts), which shows the vehicle meets the primary mission cruise speed requirement.

The Model 110 can also cruise at 35000 ft, 10,000 ft above the primary mission requirement because of the thrust required to meet the short takeoff and landing requirements. At this altitude the baseline CF34 engine would produce the thrust available versus thrust required curves show in Figure 19, assuming a throttle setting of 75%.

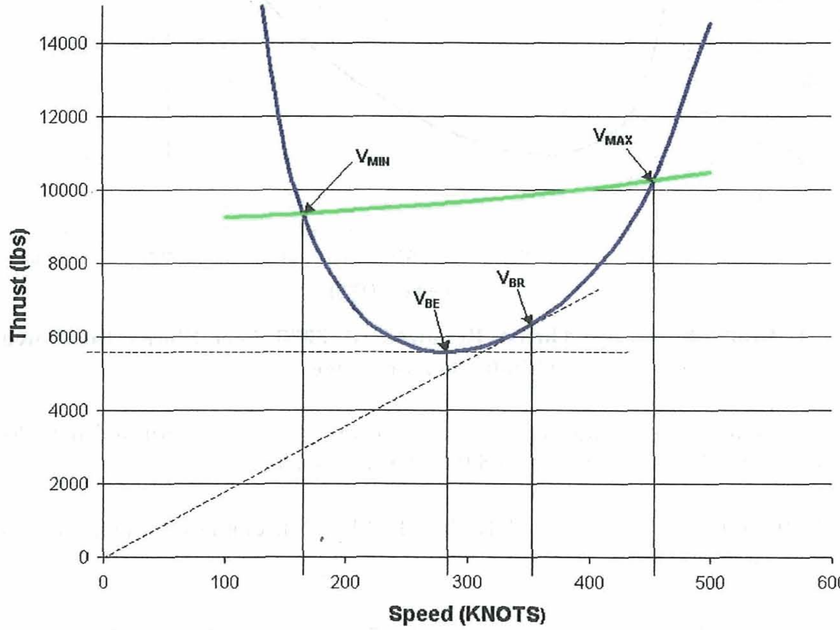


Figure 19. Thrust Available versus Thrust Required at 35000 Feet Provides Good Cruise Performance.

This scenario gives a best range speed of 350 kts, and a best endurance speed of 280 kts. The maximum rate-of-climb for the CF34 baseline occurs at a speed that surpasses the FAA mandated "speed limit" of 250 kts at both sea level and 5000 feet as shown in Figure 20. Since, in this case, the maximum allowable rate-of-climb occurs at 250 kts, it is 6,370 fpm for sea level takeoff, and 5,540 fpm for a 5,000 ft field elevation takeoff.

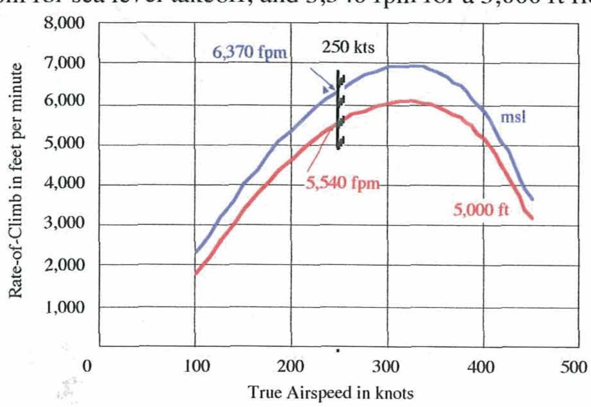


Figure 20. Maximum Rate of Climb at Low Altitude is Limited by the FAA 250 Knot Speed Limit.

Takeoff and Landing Performance

In order to ensure the Model 110 satisfies the STOL requirements, takeoff and landing performance were closely analyzed. Several takeoff situations were considered, beginning with the standard takeoff procedure. Assuming all engines are operating, the three engine options give the takeoff distances shown in Table 10, for the various throttle settings.

Table 10. Takeoff Performance by Engine Varies.

CF34-3; 4 Engines, W/S = 75 lb/ft²

Throttle	75%	85%	100%
Distance	1447 ft.	1204 ft.	952 ft.
Ground Roll	916 ft.	799 ft.	671 ft.
T/W	.32	.37	.43

ALF502R-3A; 4 Engines, W/S = 73 lb/ft²

Throttle	75%	85%	100%
Distance	2361 ft.	1917 ft.	1492 ft.
Ground Roll	1316 ft.	1143 ft.	954 ft.
T/W	.19	.22	.26

TF34-100A; 4 Engines, W/S = 74 lb/ft²

Throttle	75%	85%	100%
Distance	1748 ft.	1446 ft.	1235 ft.
Ground Roll	1057 ft.	921 ft.	772 ft.
T/W	.23	.32	.38

It should be noted that the ALF502 must be at least 85% thrust lever setting to meet the primary mission requirement of 2000 ft takeoff distance; whereas, both the CF34 (baseline) and TF34 can meet the requirement at a 75% throttle setting. The lower throttle setting is preferred, since it reduces engine-related noise, which is a serious consideration at most commercial airports.

In addition to a normal takeoff pattern, the FAR mandated one engine inoperative (OEI) performances were analyzed as well. The takeoff distances with one engine inoperative are substantially longer than the distances with all engines operating, due to the loss of the external blowing effect, as can be seen in Table 11.

Table 11. One Engine Inoperative Takeoff Performance Meets FAR 25.

CF34-3; 3 Engines, W/S = 75 lb/ft²

Throttle	75%	85%	100%
Distance	2267 ft.	1852 ft.	1447 ft.
Ground Roll	1261 ft.	1096 ft.	916 ft.
T/W	.24	.27	.32

ALF502R-3A; 3 Engines, W/S = 73 lb/ft²

Throttle	75%	85%	100%
Distance	4664 ft.	3249 ft.	2361 ft.
Ground Roll	1838 ft.	1586 ft.	1316 ft.
T/W	.14	.16	.19

TF34-100A; 3 Engines, W/S = 74 lb/ft²

Throttle	75%	85%	100%
Distance	2847 ft.	2269 ft.	1748 ft.
Ground Roll	1464 ft.	1269 ft.	1057 ft.
T/W	.21	.24	.28

The ALF502 cannot meet the primary mission requirement of 2,000 ft, even with a 100% thrust lever setting. The TF34 can only meet it with 100%. The CF34 has the best performance in this category, meeting the

requirement even at 85%. However, it also exceeds 2000 ft takeoff distance at 75%, which would be the standard operating setting during takeoff.

For the baseline ESTOL configuration, meeting the required 2000 ft landing distance requirement is not a concern, as seen in Table 12. The table also shows the various speeds the aircraft will be traveling at during the landing.

Table 12. Baseline ESTOL Landing Performance Meets Mission Requirements.

	Approach	Flare	Land	Brake
Speed (kts.)	71	68	60	44
Distance (ft.)	316	456	230	89

All applicable FARs are met, including the obstacle clearance. The maximum lift coefficient is 6.65, with a deflection of 40° on the flaps. The throttle setting is at 75% for noise reduction purposes. When comparing the three engine options, it can be seen that all three engines meet the primary mission landing distance requirement . A summary of these results is shown in Table 13.

Table 13. Landing Performance for Each Engine Option Meets Mission Requirements.

	CF34	TF34	ALF502
FAR Field Length (ft.)	1818	1826	1835
T/W	0.42	0.36	0.29
W/S (lb/ft^2)	58.8	58.6	58.0

These distances assume that all engines are operating at a standard throttle setting of 75%.

Airport Congestion Study

In addition to the nominal design of a regional airliner, the SOW also requested a continuation of the airport congestion study. This section details results to date. As seen by the map in Figure 21, which was provided by NASA, there are a large number of airports in the United States capable of supporting ESTOL aircraft. Many of these are underutilized.

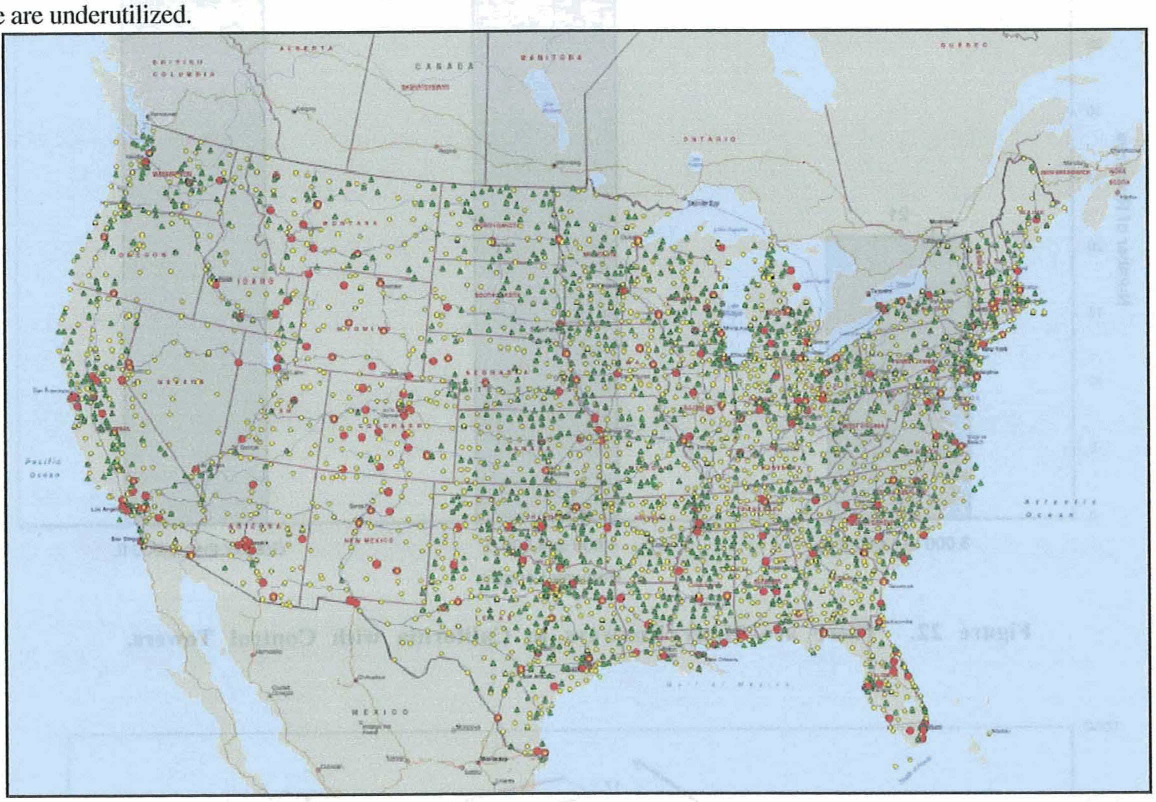


Figure 21. There is No Shortage of Runways in the United States.

Faced with the large amount of data provided, the study was narrowed to the state of California. Four factors were used in classifying runways: runway length, runway ramp weight, commercial flights, and the existence of a control tower. These factors were chosen due to their applicability to commercial traffic. The runway ramp weight is a measure of how big an airplane can land at the airport in question. This was an important statistic, since many of the smaller airports cannot accommodate larger jet transports. By ensuring the Model 110 TOGW is flexible, additional airports become available for use.

The data were first grouped into two classes: tower and non-tower airports. Figure 22 shows the number of runways available in California with control towers broken down by length, with the 4,000 to 6,000 ft runways being of primary interest to this study. These airports were investigated further, with their statistics compiled into a database included on the PowerPoint CD.

Many of the underutilized runways have low ramp weights. A trade study was conducted to see how TOGW might be reduced while still meeting all primary mission requirements. Figure 23 shows some of the results of this trade study.

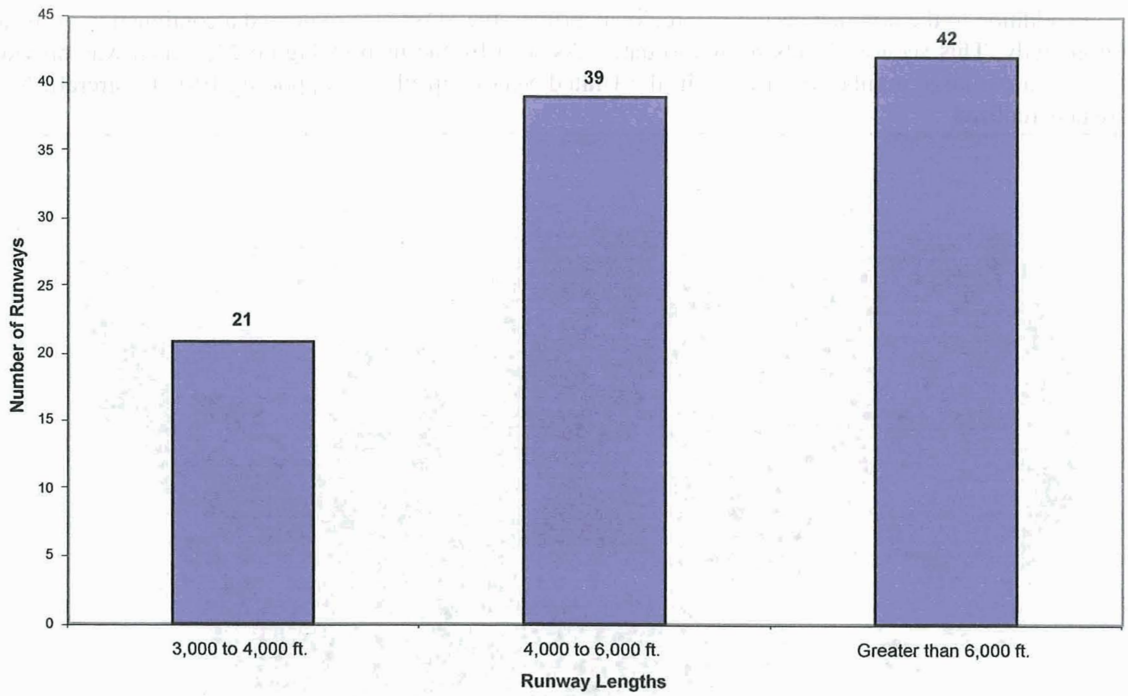


Figure 22. There are Many Runways in California with Control Towers.

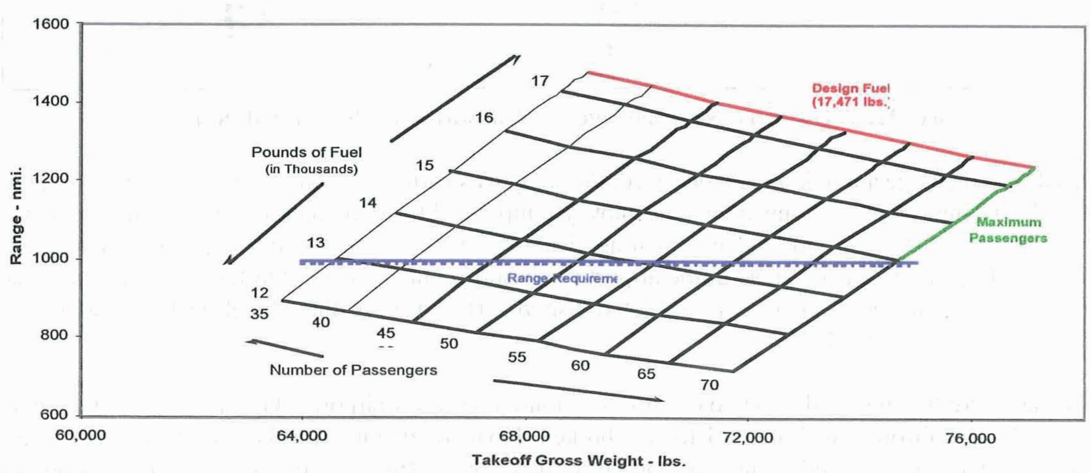


Figure 23. TakeOff Gross Weight and Range Vary With Payload and Fuel Load.

By reducing ramp weight, additional runways become useable. This includes runways at smaller airports in suburban areas, which would allow those airports to absorb additional traffic. By altering the mission profile,

reducing range, or passenger complement, even more airports become accessible. Some ideas were explored; their results are contained in the database. The early results of the California study are promising. Many runways are available for use by the Model 110. Some of these runways are near areas of heavy congestion, such as SFO and LAX. Those runways could be used to reduce the load of the congested airports, which might lessen delays.

Taking the early results of the California study, and extending them to the rest of the United States, it becomes clear that there is a large potential market for ESTOL aircraft, as can be seen in Figure 21. Using ESTOL type aircraft, as well as modifying the hub-and-spoke system, congestion at major airports could be reduced, which would allow for more efficient use of space, and help decrease delays. The system, as it has been presented here, appears to be economically as well as technologically feasible, although more detailed business studies may be required.

CONCLUSIONS AND RECOMMENDATIONS

The Model 110 is, at this stage, only a notional design. Many unanswered questions remain about the system concept as well as the vehicle design. This phase of the work also showed the need for a cohesive, generic high lift system performance methodology including powered lift effects.

A detailed business study would be helpful in determining the economic feasibility of the new regional jet transport system, as well as the production of the vehicle. In order to finalize the design of the Model 110, addition information would be required about the propulsion system, as well as the high-lift system. At a higher level, companion studies should be performed to define airport traffic area operations and most likely runway lengths to be required.

Presentation to Boeing/Long Beach C-17 Staff
Describing
the History of and Plans for

the
NASA/Cal Poly/Boeing Advanced Concepts Design Consortium

September 20, 2002

Consortium Goal

- Create an environment in which students can apply their recently learned technical knowledge to real-world challenges in an industrial advanced concepts department setting.
- Provide first-rate new engineers to industry and Government who need little or no initial on-the-job training (try-before -you-buy).
- Augment industry and Government advanced concepts organizations by providing timely, quality responses to internal and customer design study needs.
- Improve cross-fertilization of new ideas between all participating organizations.

Cal Poly's Aircraft Design Lab

Home of award-winning aircraft design sequence for forty years

1,600 square feet, extensive design text & report reference library, 11 PCs, 9 Macs, LAN, 6 printers, 1 plotter, audio/video options

AIAA Competition Results

YEAR	COMPETITION	INSTRUCTOR	BID	FIRST	SECOND	THIRD
2002/2003	Ultra Heavy Lift	Hall	yes		to be determined	
2002/2003	Reusable Launch Vehicle	DeTurris	yes		to be determined	
2001/2002	LO Interdictor	Hall	yes	1		1
2001/2002	HALE UAV	Hall	yes			1
2000/2001	Common Support	Hall	yes		1	
2000/2001	Hypersonic	DeTurris	yes	1		
1999/2000	Cruise Missile Carrier	Hall	yes	1		
1998/1999	Super STOL COD	van't Riet	yes	1		
1997/1998	UCAV	van't Riet	yes		1	
1996/1997	Regional Amphibian	van't Riet	yes	1	1	
1995/1996	HALE UAV (Tier II+)	van't Riet	yes	1	1	
1994/1995	Space Transportation	van't Riet	yes		1	1
1993/1994	Commercial Transport	van't Riet	yes		1	
1992/1993	Global Range Transport	van't Riet	yes		1	
1991/1992	General Aviation	van't Riet	no			
1990/1991	Close Support Aircraft	Cummings	yes			1
1989/1990	Advanced Package Transport	Andreoli	yes	1		1
1988/1989	no data	Andreoli	no			
1987/1988	Drug Enforcement	Andreoli	no			
1986/1987	General Aviation Amphibian	Sandlin	yes	1		

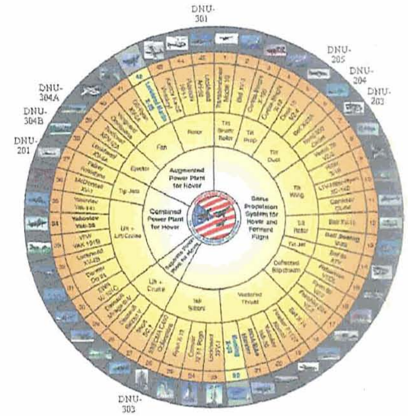
Research Grants

1999-2000 Boeing	Navy Multi-Role Endurance UAV Configuration Study
2000-2001 NASA/Ames	USB Extreme STOL Regional Airliner
2000-2001 Boeing	*Front Line Delivery System Configuration Study*
2000-2001 NASA/Ames	Mars Flyer High Altitude Drop Test Campaign 2001
2001-2002 Boeing	ESTOL Advanced Tactical Transport Civilian Demonstrator Configuration Study
2001-2002 NASA/Langley	Personal Air Vehicle Experiment Study
2001-2002 NASA/Ames	EBF Extreme STOL Regional Airliner
2001-2002 NASA/Ames	Mars Flyer High Altitude Drop Test Campaign 2002

California Polytechnic State University, San Luis Obispo

Ship-Suitable Multi-Role Endurance UAV

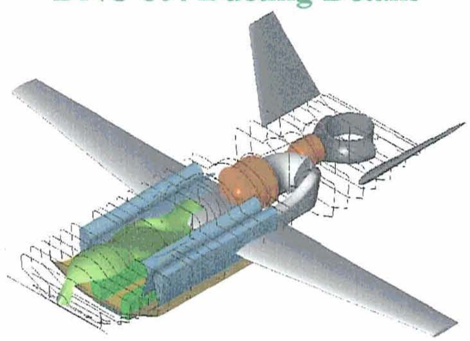
Boeing requested that Cal Poly review all possible VTOL design approaches and create configurations using the most promising ones to provide UAV strike/reconnaissance capability to all Navy air-capable ships.



NASA / Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

DNU-304 Ducting Details



This MRE configuration demonstrates the application of chordwise augmentor bays to provide VTOL capability.

NASA / Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

MRE-UAV Configuration Matrix

2100# Sensor Payload / 320kt Cruise / JSF Level LO / 15kt WOD

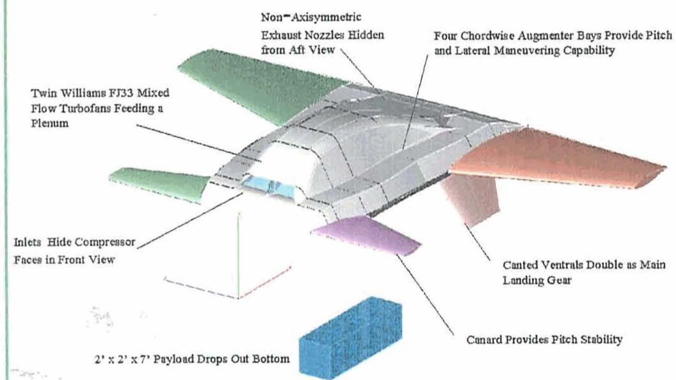
Ops: Cat/Trap Runway: 800 ft Radius: 600 nm TOGW: TBD Span: TBD Endurance: 12hr + 1/2hr Go Around Config: Wing/Body OPR: Zach Hoisington	Ops: STOL Runway: 500 ft Radius: 600 nm TOGW: TBD Span: TBD Endurance: 12hr + 1/2hr Go Around Config: Stopped Rotor Autogyro OPR: Cal Poly San Luis Obispo	Ops: VTOL Runway: 0 ft Radius: 200 nm TOGW: TBD Span: TBD Endurance: 9.5hr + 1/2hr Go Around Config: Stopped Rotor (Powered) OPR: Cal Poly San Luis Obispo
Ops: Free Deck Runway: 800 ft Radius: 600 nm TOGW: TBD Span: TBD Endurance: 12hr + 1/2hr Go Around Config: Wing/Body OPR: Zach Hoisington	Ops: STOL Runway: 500 ft Radius: 600 nm TOGW: TBD Span: TBD Endurance: 12hr + 1/2hr Go Around Config: Vectored Thrust OPR: Dave Boyer	Ops: VTOL Runway: 0 ft Radius: 200 nm TOGW: TBD Span: TBD Endurance: 9.5hr + 1/2hr Go Around Config: Lift Fan & Cruise/Lift Engine OPR: Dave Boyer
Ops: Cat/Trap Runway: 800 ft Radius: 600 nm TOGW: TBD Span: TBD Endurance: 12hr + 1/2hr Go Around Config: Flying Wing OPR: Dave Boyer	Ops: STOL Runway: 500 ft Radius: 600 nm TOGW: TBD Span: TBD Endurance: 12hr + 1/2hr Go Around Config: Tilt Wing / Tilt Propulsion OPR: Donnie Stewart	Ops: VTOL Runway: 0 ft Radius: 200 nm TOGW: TBD Span: TBD Endurance: 9.5hr + 1/2hr Go Around Config: Tilt Wing / Tilt Propulsion OPR: Aaron Kutzmann
Ops: Free Deck Runway: 800 ft Radius: 600 nm TOGW: TBD Span: TBD Endurance: 12hr + 1/2hr Go Around Config: Flying Wing OPR: Dave Boyer	Ops: STOL Runway: 500 ft Radius: 600 nm TOGW: TBD Span: TBD Endurance: 12hr + 1/2hr Go Around Config: Deflected Thrust OPR: Dave Hall	Ops: VTOL Runway: 0 ft Radius: 200 nm TOGW: TBD Span: TBD Endurance: 9.5hr + 1/2hr Go Around Config: Augmented Thrust OPR: Dave Hall
Customer Requirement	BOEING PROPRIETARY	Mission Area Analysis Desirement

NASA / Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

FLD-113 Features

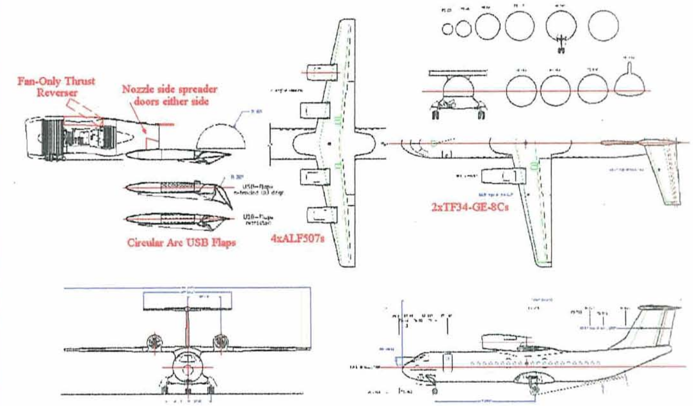
DARPA's novel Frontline Delivery System required UAV configurations to shuttle between airborne and ground bases. This configuration also used chordwise augmentor bays.



NASA / Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

2000-2001 USB ESTOL Configuration



NASA / Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Goal

- Strengthen the relationship between, Cal Poly, NASA, and Boeing
  - This will allow the students to graduate as better engineers
  - Past activities have validated this
- Secondary Goal
  - Discussion of SNI/ESTOL system concept

NASA / Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Value of a Stronger Relationship

- What you will see today will demonstrate that this type of relationship is a win - win for all parties.
  - Current relationship has allowed a free flow of ideas, information and mentoring.
  - Standard method spends a lot of time with paperwork versus education.

NASA / Cal Poly ESTOL Research Project

The Problem Posed

- Current NAS system will not stay ahead of the required growth much longer.
- Past research has pointed to the need to have a system and a vehicle that can:
  - Use runways 4,000 feet long.
  - Fly descending/decelerating SNI approaches.
  - Is economically feasible
    - Manufacturability, Operate in current and future NAS, etc.

California Polytechnic State University, San Luis Obispo

The Problem Posed (Continued)

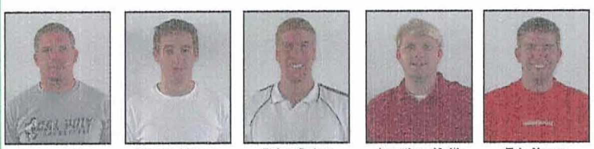
- Students were asked to design a low risk vehicle that could be used as baseline aircraft for system studies.
- The vehicle designed uses a C-17 wing scaled to a BAe-146-100 fuselage.
  - This was picked as a notional vehicle that could be developed and built without any enabling technology needing to be developed.

NASA/Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

The 2002 ESTOL Project Team

Team Advisor and Configurator: David Hall



Andrew Gibson Lead Engineer, Systems Engineering

Ben Schiltgen Propulsion

Brian Selvy Airport Congestion, Performance

Jonathan Keith Airport Congestion, Parametrics

Eric Naess Solid Modeling

Not Pictured

Leif Engen Configuration, Airport Congestion

Justin Ott Performance

Erin Clare Configuration

Edgar Salvador Propulsion

Renee Pasman Configuration

Andrea Marlowe Performance

Alicia Robertson Airport Congestion, Performance

NASA/Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

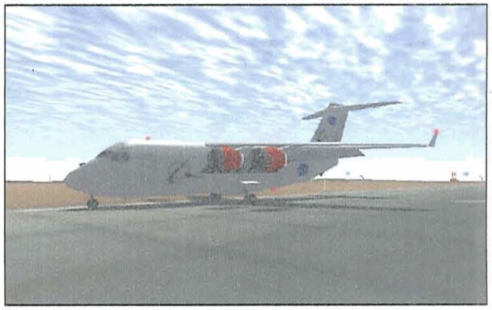
The NASA/Cal Poly ESTOL Project Team Presents The Model Model 114 Regional Airliner

NASA/Cal Poly ESTOL Research Project

Agenda

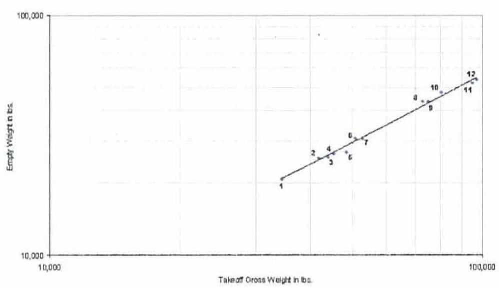
- Initial Design
- Configuration
  - Landing Gear
- Propulsion
- Performance
  - Takeoff
  - Landing
  - General
- V-n Diagram
- Airport Congestion
- Recommendations

Initial Design



Analysis of Current Regional Jets

The following Regional Jets were used to create a weight trend for the current configuration

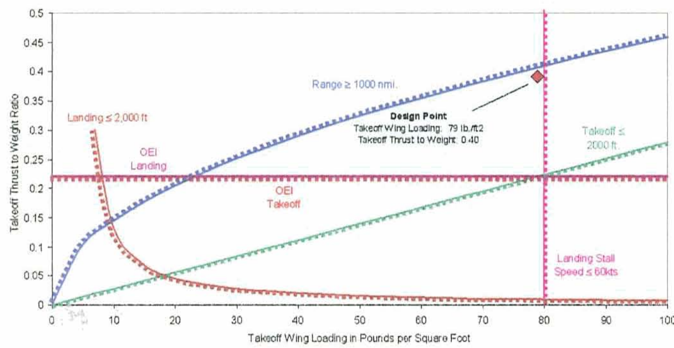


1. Fairchild Domier 328-300
2. Embraer ERJ135ER
3. Embraer ERJ135ER LR
4. Embraer ERJ145ER
5. Embraer ERJ145ER LR
6. Bombardier CRJ200 ER
7. Bombardier CRJ200 LR
8. Bombardier CRJ700
9. Bombardier CRJ700 ER
10. Bombardier CRJ900
11. BAE RJX-70
12. BAE RJX-85

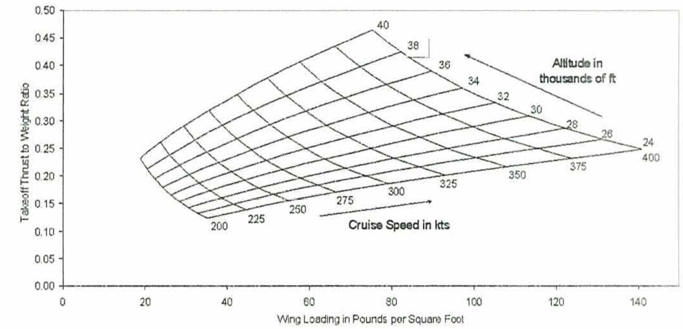
Assumptions Used for Constraint Plot Construction

- Number of Engines: Four (maintain high-lift system)
- C_{Lmax}: 6.65
- Engine Throttle (Cruise): 75%
- 0.5g deceleration on landing
- Meet All FAR Part 25 Takeoff and Landing Constraints

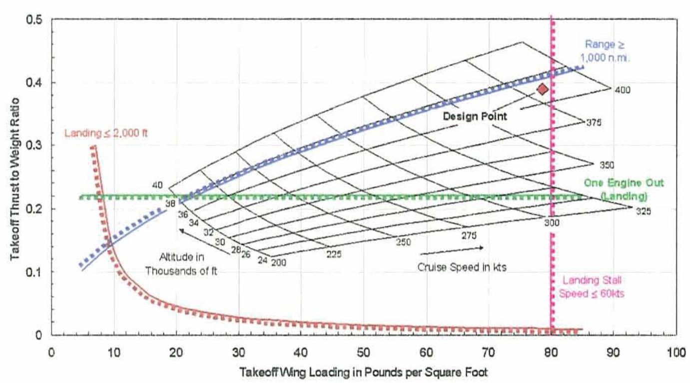
Design Constraint for ESTOL Aircraft



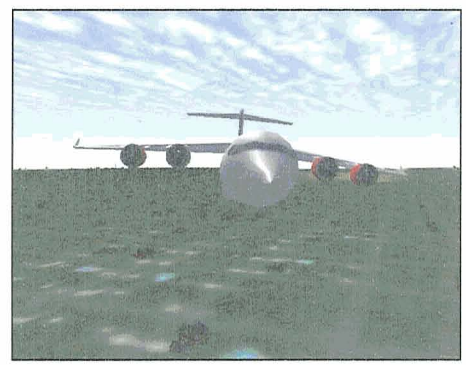
Variation in Wing Loading and Thrust to Takeoff Gross Weight as Velocity and Altitude Vary in Cruise Conditions



Design Point Determination Using Cruise Trade Study



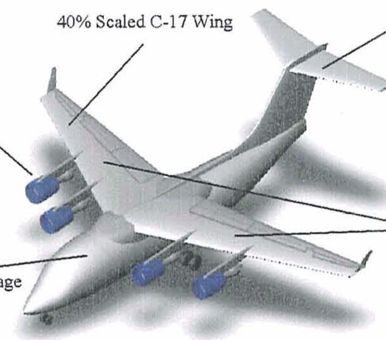
Configuration



Configuration Overview

- Features Chart
- Fuel Configuration
- Weight Sizing and Results
- Payload Range Diagram
- Tail Sizing/Wing Mounting Structure

Current Baseline ESTOL Features



Takeoff Gross Weight of 77,150 lb.

Alternative Fuselages

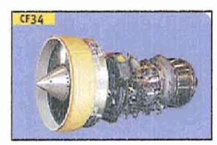
Antonov An-74TK-300
TOGW 82,670 lbs.
Accommodation for 60 to 68 passengers

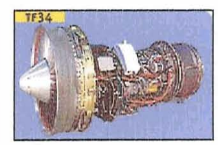
ATR 72-500
TOGW 47,400 lbs
Accommodation for up to 64 passengers

Bombardier Dash-8 Q400
TOGW 43,000 lbs.
Accommodation for 70 passengers

IPTN N-250 Gatut Koco
TOGW 54,674 lbs.
Accommodation for up to 68 passengers

Alternative Engines

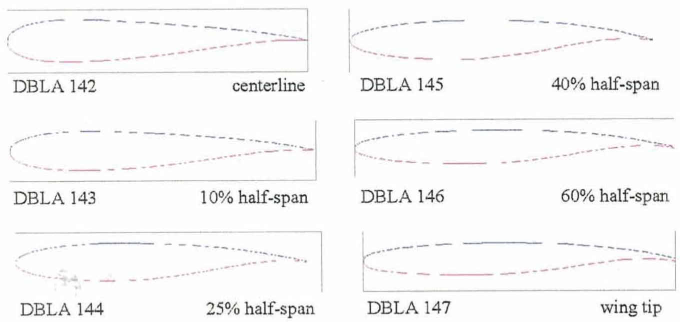




Engine		CF34-3	TF34-100A	ALF502R-3A
Installed Thrust (SL)	lb.	8,288	7,200 .	5,800
Weight	in.	1,478	1,440	1,283

Wing Layout

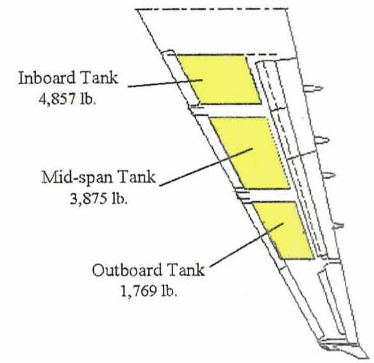
- 6 different airfoils blended over span



California Polytechnic State University, San Luis Obispo

Fuel Layout

- Volume method
  - Used 6 different airfoils, blended over the span
- Applicable FARs
  - No fuel above cabin
  - Butt planes over engine pylons
- Final layout
  - Integral Tanks
  - Total fuel: 21,002 lb.



NASA/Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Weight Sizing and Results

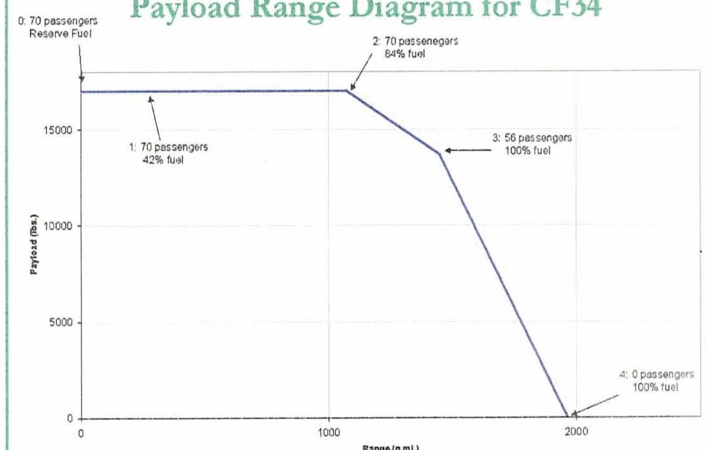
	CF34	TF34	ALF502
Structure (lb.)	25,788	25,788	25,788
Propulsion (lb.)	6,614	6,462	5,834
Equipment (lb.)	10,046	10,046	10,046
Total Empty Weight (lb.)	**42,449**	**42,297**	**41,669**
Fuel (lb.)	17,641	17,000	16,000
Payload (lb.)	17,060	17,060	17,060
Takeoff Gross Weight (lb.)	**77,150**	**76,356**	**74,728**

Primary Source: Raymer (3rd Edition)
Secondary Sources: Roskam, Nicolai, Torenbeek

NASA/Cal Poly ESTOL Research Project

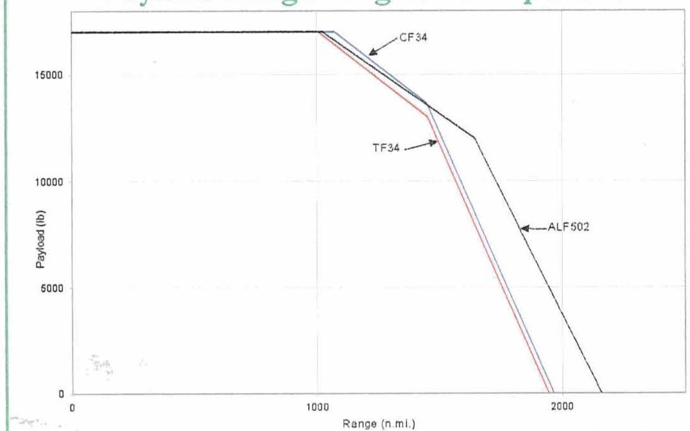
California Polytechnic State University, San Luis Obispo

Payload Range Diagram for CF34



NASA/Cal Poly ESTOL Research Project

Payload Range Diagram Comparison



Tail Sizing

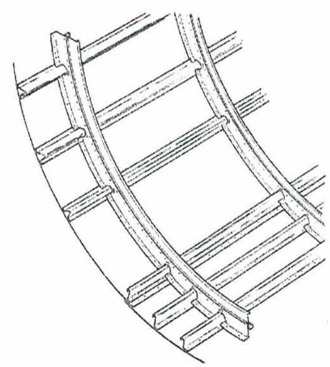
- BAe-146-100 empennage sufficient
- Check for crosswind capabilities pending

Wing Comparison

- Wing is 24% larger, 20.4% heavier than BAe-146-100 wing.
- Extra weight no concern, later models of –100 can support it.

	Model 114	BAe-146-100
Weight (lb)	5413	4995
Area (ft^2)	1030	832
Distance between spars at centerline (ft)	9.5	4.5

Fuselage Structure



- Need to add 2 new frames
  - 8.5 inches behind frame #13 (FS 399)
  - 6 inches in front of frame #19 (FS 516)
- Treat frames 14 and 16 as normal, no/little weight increase

Landing Gear

Landing Gear Configuration

Main Gear

- 15° tip back angle to C.G.
- 14° tail strike angle
- 55% of MAC
- Static Load = 70,251 lb.

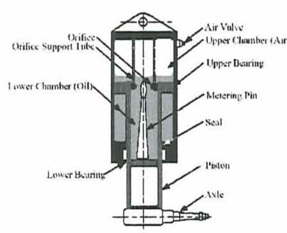
Nose Gear

- Static Load = 6,899 lb.
- Self-centers ±20°
- Steerable through ±70°
- Castors ±180°
- Steered by cockpit hand-wheels

Overall Landing Gear Weight: 2,791 lb

Shock Absorbers

- Oleo/pneumatic fitted to each unit
- Compression Ratios:
  - Static to Extended = 4/1
  - Compressed to Static = 3/1



•Main

Load Extended = 8,781 lb.
Load Static = 35,126 lb.
Load Compressed = 105,377 lb.

•Nose

Load Extended = 1,725 lb.
Load Static = 6,899 lb.
Load Compressed = 20,696 lb.

Tire Selection

Nose Gear

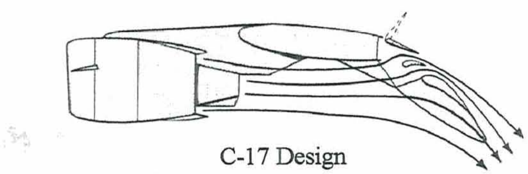
	New DR15840T	Old DR15856T
Type	VII	VII
Tire Size	24x7.7	24x7.7
Ply Rating	14	14
Speed Rating (mph)	190	225
Max Load (lbs)	8,200	8,200
Typical Weight (lbs)	29.4	27.4

Main Gear

	New DR11739T	Old DR11748T
Type	VII	VII
Tire Size	39x13	39x13
Ply Rating	18	24
Speed Rating (mph)	190	210
Max Load (lbs)	19,400	27,400
Typical Weight (lbs)	89.30	110.00

Propulsion Objectives

- Baseline ESTOL uses the C-17 high lift system
- Finding the *best way* to scale the system down to work on a regional airliner

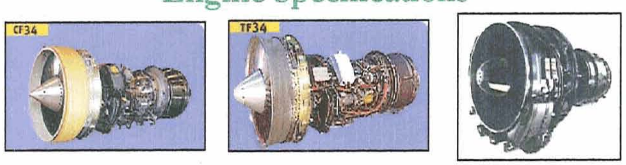


C-17 Design

Propulsion Options

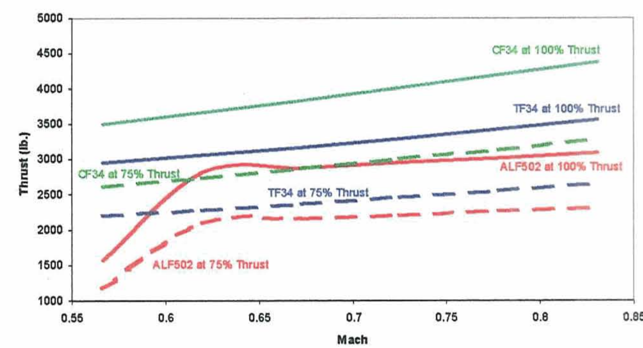
- Aircraft take-off gross weight determined decision for total installed thrust
- CF34, TF34, ALF502 picked for good SFC, at altitude thrust, and BPR
- Four engines for increased blown flap area, improved engine out performance, and to emulate the C-17

Engine Specifications



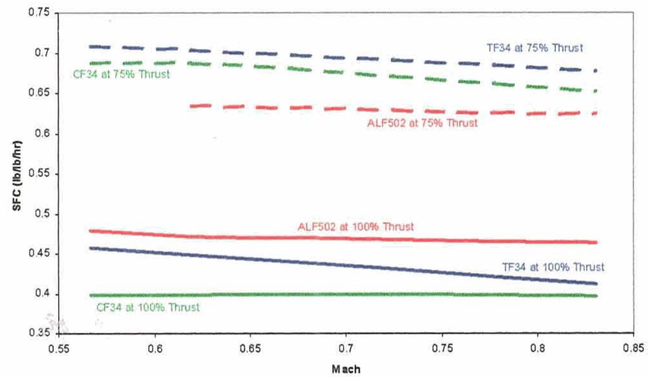
Engine		CF34-3	TF34-100A	ALF502R-3A
Uninstalled Thrust (SL)	lb.	9,270	8,100	6,570
Installed Thrust (SL)	lb.	8,288	7,200 .	5,800
SFC (Cruise)	lb/lb/hr	0.682	0.700	0.640
BPR		6.2	6.2	5.6
Weight	in.	1,478	1,440	1,283
Length	in.	103	100	56.8

Installed Thrust versus Mach 35,000 ft.



California Polytechnic State University, San Luis Obispo

Installed SFC versus Mach 35,000 ft.

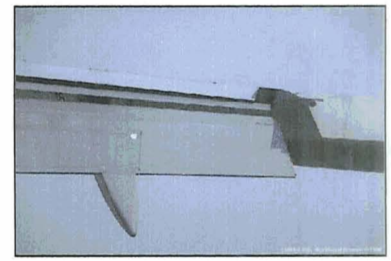


NASA/Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

High Lift System

ESTOL flaps must be titanium to withstand heat from engine exhaust

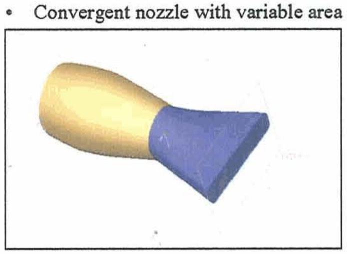


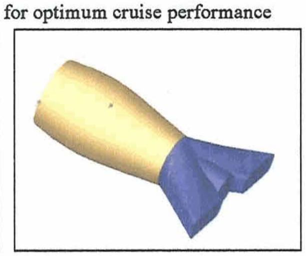
NASA/Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Nozzle Options

- Modify scaled down C-17 high-lift system to improve performance
- Design dependent on engine core exhaust temperature
- Nozzle design will allow maximum blown area
- Convergent nozzle with variable area for optimum cruise performance



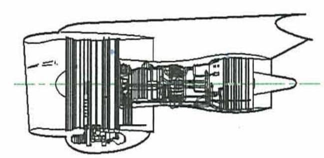


- Mixed exhaust design looks promising with preliminary calculations
- Design can be modified to increase blown area and/or reduce drag

NASA/Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Nacelle



Baseline Nacelle Design

Design Features

- Optimize inlet area
- Optimize for thrust reversal
- Minimize drag
- Easy maintenance access

Nacelle Estimations	CF34	TF34	ALF502
Diameter	47.26 in.	44.60 in.	38.93 in.
Inlet Area	1227.93 in^2.	1093.6 in^2.	833.21 in^2.

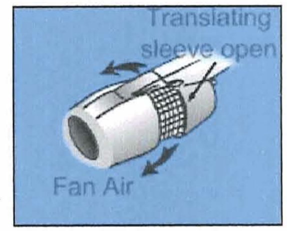
NASA/Cal Poly ESTOL Research Project

Future Engine Placement Considerations

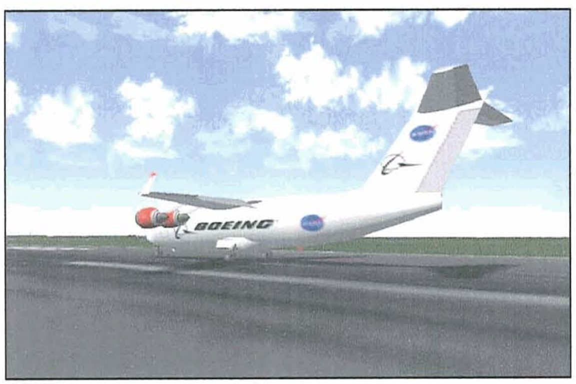
- Currently scaled to C-17 location
- Potential areas for trade studies
  - Noise
  - Temperature
  - Structure
  - Blown flap area
  - ALF502 option

Thrust Reversal

- Cascade reversal system
- May include core flow depending on nozzle design



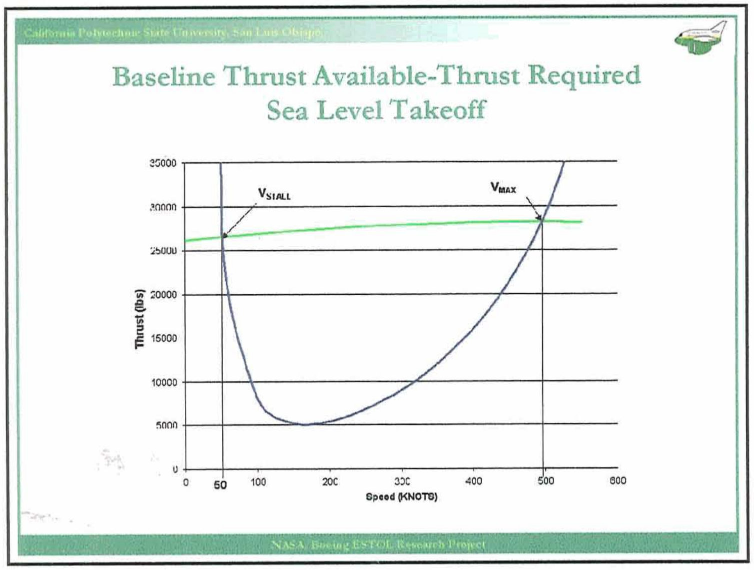
Performance

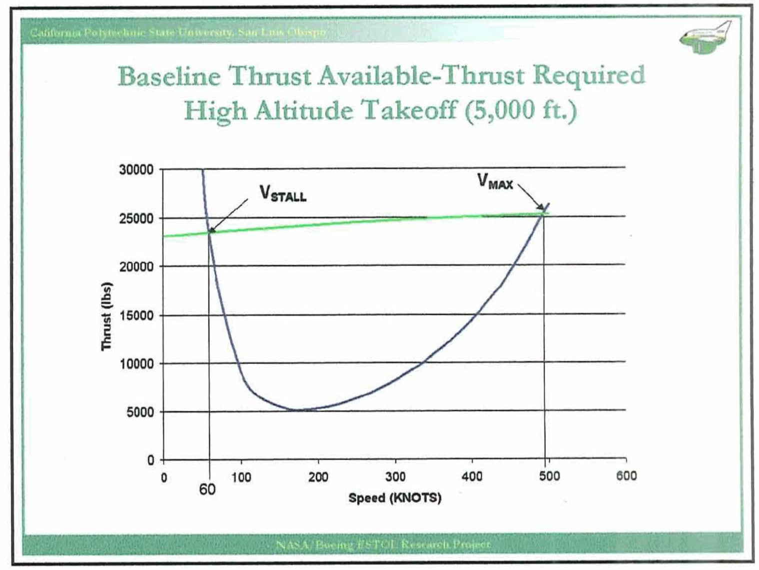


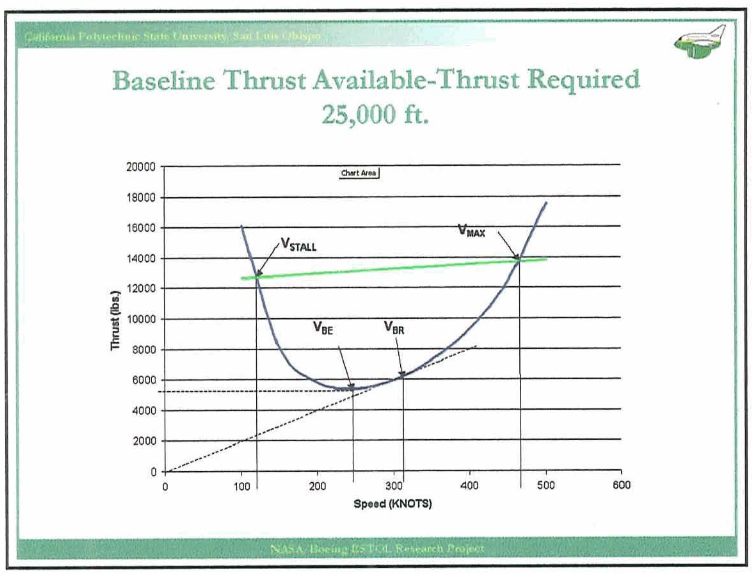
Drag Buildup Method and Baseline Aerodynamic Results

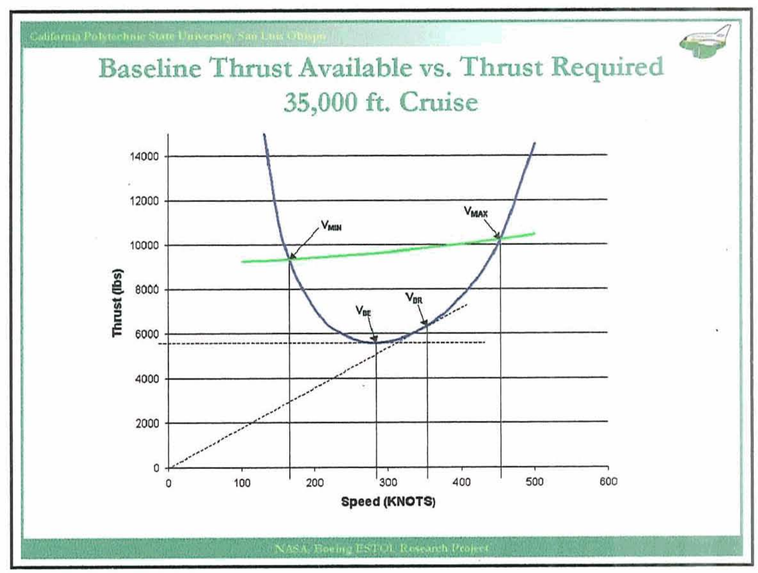
- An estimated parasite drag coefficient was calculated for each basic airplane component.
  (Cummings, R., "Aerodynamic Drag," Cal Poly, San Luis Obispo, CA, Feb. 2001.)
- A compressibility drag correction was then performed using the Prandtl-Glauert rule.
- Induced drag coefficients were calculated for the wing.
- A 10% correction factor was added to $C_{D\,o}$ to account for interference, excrescence, and engine drag.

	Takeoff	Cruise	Landing
$C_{D\,tot}$	1.0499	0.0459	1.2703
$C_{L\,opt.}$	4.25	0.45	4.68
L/D	4.45	10.87	4.05
Transport Efficiency Factor	0.48	6.98	0.37


California Polytechnic State University, San Luis Obispo
Baseline Thrust Available-Thrust Required
Sea Level Takeoff
VSTALL
VMAX
Thrust (lbs)
Speed (KNOTS)
NASA/Boeing ESTOL Research Project

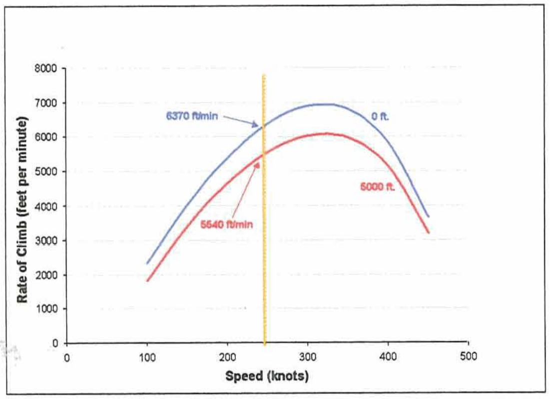

California Polytechnic State University, San Luis Obispo
Baseline Thrust Available-Thrust Required
High Altitude Takeoff (5,000 ft.)
VSTALL
VMAX
Thrust (lbs)
Speed (KNOTS)
NASA/Boeing ESTOL Research Project


California Polytechnic State University, San Luis Obispo
Baseline Thrust Available-Thrust Required
25,000 ft.
Chart Area
VSTALL
VMAX
VBE
VBR
Thrust (lbs)
Speed (KNOTS)
NASA/Boeing ESTOL Research Project


California Polytechnic State University, San Luis Obispo
Baseline Thrust Available vs. Thrust Required
35,000 ft. Cruise
VMIN
VMAX
VBE
VBR
Thrust (lbs)
Speed (KNOTS)
NASA/Boeing ESTOL Research Project

California Polytechnic State University, San Luis Obispo

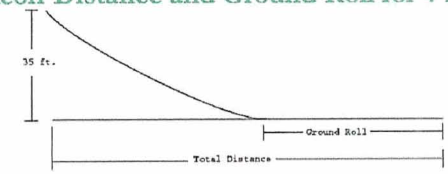
Baseline Rates of Climb



NASA/Boeing ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Takeoff Distance and Ground Roll for 4 Engines



CF34-3; 4 Engines, W/S = 75 lb/ft²

Throttle	75%	85%	100%
Distance	1447 ft.	1204 ft.	952 ft.
Ground Roll	916 ft.	799 ft.	671 ft.
T/W	.32	.37	.43

ALF502R-3A; 4 Engines, W/S = 73 lb/ft²

Throttle	75%	85%	100%
Distance	2361 ft.	1917 ft.	1492 ft.
Ground Roll	1316 ft.	1143 ft.	954 ft.
T/W	.19	.22	.26

TF34-100A; 4 Engines, W/S = 74 lb/ft²

Throttle	75%	85%	100%
Distance	1748 ft.	1446 ft.	1235 ft.
Ground Roll	1057 ft.	921 ft.	772 ft.
T/W	.23	.32	.38

NASA/Boeing ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Takeoff Distance and Ground Roll for Engine Out

CF34-3; 3 Engines, W/S = 75 lb/ft²

Throttle	75%	85%	100%
Distance	2267 ft.	1852 ft.	1447 ft.
Ground Roll	1261 ft.	1096 ft.	916 ft.
T/W	.24	.27	.32

ALF502R-3A; 3 Engines, W/S = 73 lb/ft²

Throttle	75%	85%	100%
Distance	4664 ft.	3249 ft.	2361 ft.
Ground Roll	1838 ft.	1586 ft.	1316 ft.
T/W	.14	.16	.19

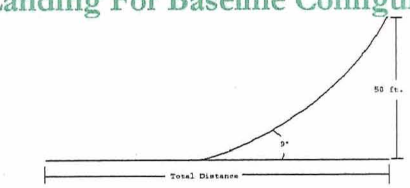
TF34-100A; 3 Engines, W/S = 74 lb/ft²

Throttle	75%	85%	100%
Distance	2847 ft.	2269 ft.	1748 ft.
Ground Roll	1464 ft.	1269 ft.	1057 ft.
T/W	.21	.24	.28

NASA/Boeing ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Landing For Baseline Configuration



Externally blown double-slotted Fowler flaps used

$\delta_{flap} = 40°$ $C_{L_{Max}} = 6.65$

	Approach	Flare	Land	Brake
Speed (kts.)	71	68	60	44
Distance (ft.)	316	456	230	89

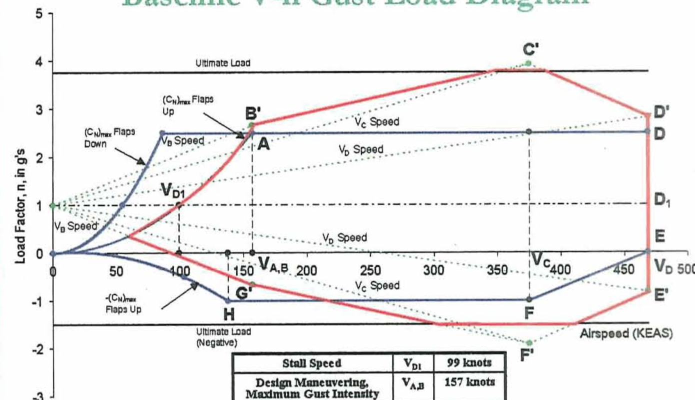
Total Landing Distance = 1091
Total FAR Field Length = 1818 ft.

NASA/Boeing ESTOL Research Project

Landing Performance Comparison

	CF34	TF34	ALF502
FAR Field Length (ft.)	1818	1826	1835
T/W	0.42	0.36	0.29
W/S (lb/ft²)	58.8	58.6	58.0

Baseline V-n Gust Load Diagram



Stall Speed	V_{D1}	99 knots
Design Maneuvering, Maximum Gust Intensity	$V_{A,B}$	157 knots
Cruise Speed	V_C	380 knots
Diving Speed	V_D	468 knots

Airport Congestion

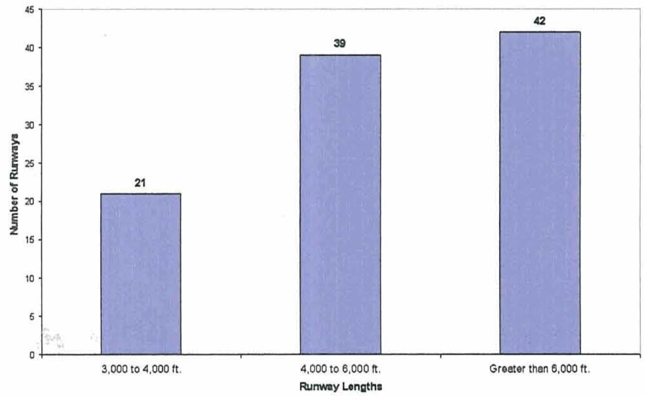
Study of California

Criteria used in the California study:

- County Population
- Runway Size
- Daily Commercial Flights
- Existence of Control Tower

California Polytechnic State University, San Luis Obispo

Comparison of Public Runways (with Control Tower) in California



NASA/Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Study of California

Runway Maps Created Using County Boundaries and Daily Commercial Traffic

•Most available non-trafficked runways are in sparsely populated regions.

•LAX and SFO within proximity to under-used runways.

•Problems exist, however, to efficiently connect under-used and over-used airports.

NASA/Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Available Airports for the Model 114

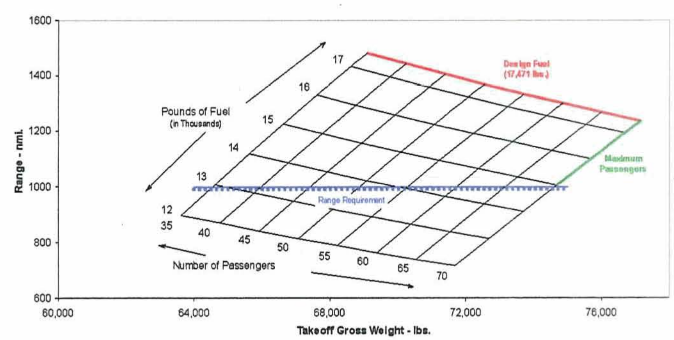
•Usable Airports must have:

- •Runway lengths of 4,000 ft. or greater.
- •Double wheel runway weight limitations in excess of 77,150 lb.
- •Control tower.

NASA/Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Variation in Takeoff Gross Weight and Range as the Number of Passengers and Amount of Fuel Varies



NASA/Cal Poly ESTOL Research Project

Study Recommendations and Questions

•Exit temperature and velocities of engine needed for more in-depth propulsion analysis.

•More C-17 data and specifications needed (flaps, pylons, nacelles, etc.).

•Cost analysis.

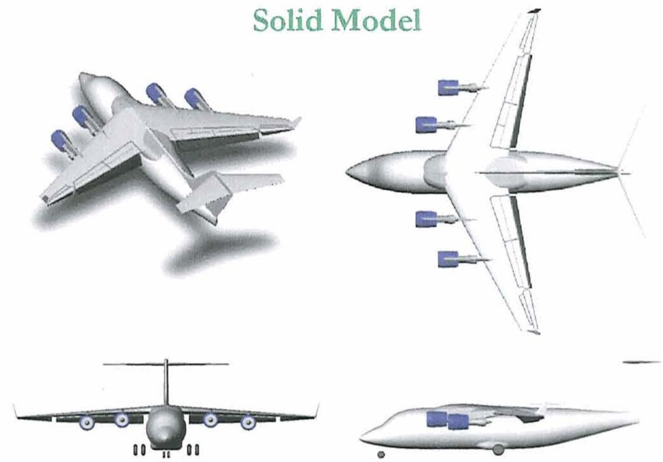
•What are we missing, in the vehicle or system concept?

•Economics and manufacturing issues.

•What issues are we not thinking about?

California Polytechnic State University, San Luis Obispo

Solid Model



NASA / Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Defining the Next Steps

- Cal Poly would create an "entity" that NASA and Boeing could fund.
  - Each partner would fund this entity @ $ 30K/yr.
  - Students would be given real world problems to be studied.
  - Work would be non-proprietary.

NASA / Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Other Issues

- Create a Council of the partners would decide/suggest what projects to work on?
- Should we add other partners?
- Development of Summer jobs for Students?

NASA / Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

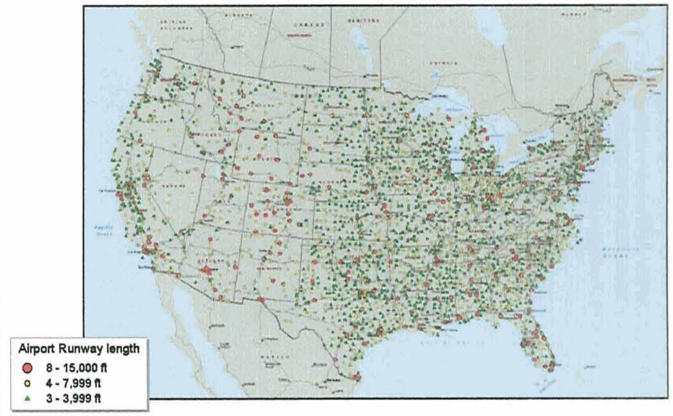
Background

- Growth of current system will end in gridlock
- Current solutions only moves problem to the right, does not solve the problem

NASA/Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Airports That Can Support ESTOL Aircraft



NASA/Cal Poly ESTOL Research Project

California Polytechnic State University, San Luis Obispo

Simultaneous Non-Interfering (SNI) Approaches

Boeing further developed this concept in their 1998 NASA report *"Rotorcraft Requirements in the Next Generation ATM System"*.

NASA/Cal Poly ESTOL Research Project

Geometry

ITEM	UNITS	C-17 SCALED WING	HORIZONTAL	DORSAL
Areas	sq.ft.			
Reference		1,030.0	256.0	227.6
Exposed		826.2	246.4	220.4
Wetted		1,697.0	501.5	448.4
Span	ft.	87.1	36.3	15.6
Aspect Ratio	-	7.371	5.157	1.065
Thickness-to-Chord Ratio	-			
Root	-	0.153	0.090	0.090
Tip	-	0.122	0.090	0.090
Taper Ratio	-	0.244	0.388	0.678
Chords	ft.			
Root		18.93	10.13	17.42
Root Exposed		17.08	9.92	17.11
Tip		4.72	3.93	11.81
Mean Geometric		13.25	7.50	14.80
Sweeps	°			
Leading Edge		28.4	23.6	39.1
Quarter Chord		24.6	19.4	35.9
Half Chord		20.6	14.9	32.4
Three-Quarter Chord		16.4	10.2	28.5
Trailing Edge		12.0	5.4	24.5
Tail Arm	ft.		42.17	34.13
Tail Volume	-		0.791	0.087
Dihedral (+ up)	°		-	-
Incidence (+ nose up)	°		-	-
Twist or Washout (+ nose up)	°		-	-
Cant	°		-	-

Body	Length	Width	Height	Surface Area	Wetted Area
	ft.	ft.	ft.	sq.ft.	sq.ft.
Fuselage	79.29	11.79	11.79		
Nacelle (each)	12.00	5.00	5.00		
Landing Gear Pods	11.50	2.50	2.50		

Aerodynamics

	TakeOff	Mid-Cruise	Landing
Lift Coefficient			
Maximum Clean		2.02	
Maximum Flapped	6.655	-	6.655
Operating	4.247	0.34	4.678
Drag Coefficient			
Parasite	0.0336	0.0274	0.1820
Viscous due to Lift	-	0.0000	-
Inviscid due to Lift	0.9278	0.0064	1.1280
Total	0.9614	0.0338	1.3100
Lift-to-Drag Ratio	4.42	13.01	3.57
Wing Efficiency Factor		0.993	
Airplane Efficiency Factor	0.839	0.876	0.838
Thrust-to-Weight Ratio	0.347	0.124	0.364
Wing Loading in psf	74.90	66.99	71.51
Transport Efficiency Factor		6.197	

Weight Estimate Evolution

INITIAL ESTIMATE

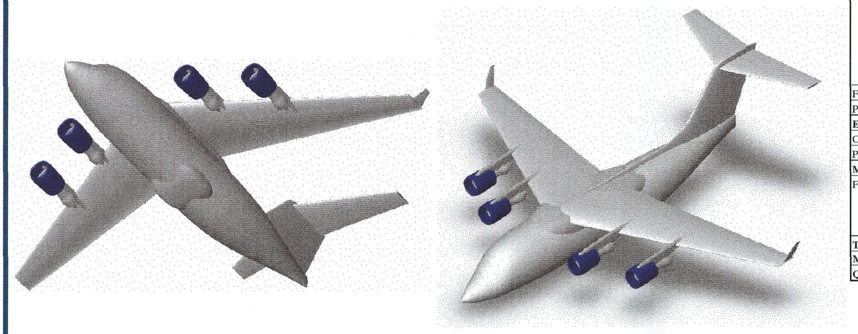
ITEM	HS146 WEIGHT #	WEIGHT #	Initial Shotgun	Nicolai #1	Raymer	Roskam	Torenbeek	DHC Conventional	Nicolai #2	Consensus Weights (#)
Wing			7,348	2,466	6,067	2,326	5,200	3,101	3,759	3,759
Horizontal			1,682	1,704	740	182	1,021	698	699	1,021
Vertical			1,498	633	793	143	913	477	1,440	913
Fuselage			3,921	520	6,062	2,051	2,116	6,751	12,586	12,586
Nacelles			252	242,136	1,616	2,452	1,340	1,757	1,340	1,340
Landing Gear			1,695	2,513	3,503	1,961	9,047	1,634	2,513	2,513
Nose										
Mains										
Pods				251	251		292			292
Structure			**16,396**	**250,223**	**19,032**	**9,115**	**19,929**	**14,418**	**22,337**	**22,424**
Surface Controls			1,265	14	672	444	1,864	1,261	88	1,864
Ailerons										
Flaps										
Inboard										
Outboard										
Slats										
Inboard										
Outboard										
Elevators										
Rudders										
Fixed Equipment			3,573	2,057	7,169	108	11,022	2,138	9,968	9,968
Propulsion Group			4,800	7,642	1,562	6,835	7,436	6,835	6,835	6,835
Empty	**43,000**	**41,860**	**26,034**	**259,936**	**28,435**	**16,502**	**40,251**	**24,652**	**39,228**	**41,091**
Crew	920	920	920	920	920	920	920	920	920	920
Passengers	17,942	16,100	16,100	16,100	16,100	16,100	16,100	16,100	16,100	16,100
Maximum Zero Fuel Weight	**61,250**	**58,880**	**43,054**	**276,956**	**45,455**	**33,522**	**57,271**	**41,672**	**56,248**	**58,111**
Fuel	13,250	22,837	38,663	(195,239)	36,262	48,195	24,446	40,045	25,469	23,606
Takeoff Gross	74,500	81,717	81,717	81,717	81,717	81,717	81,717	81,717	81,717	81,717
Max Landing Weight	**71,850**	**77,150**	**73,984**	**120,765**	**74,465**	**72,078**	**76,828**	**73,708**	**76,623**	**76,996**

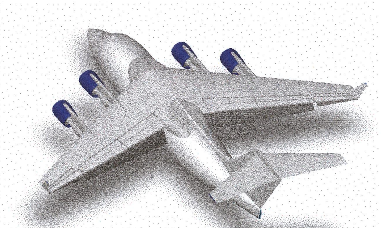
Mission Profile

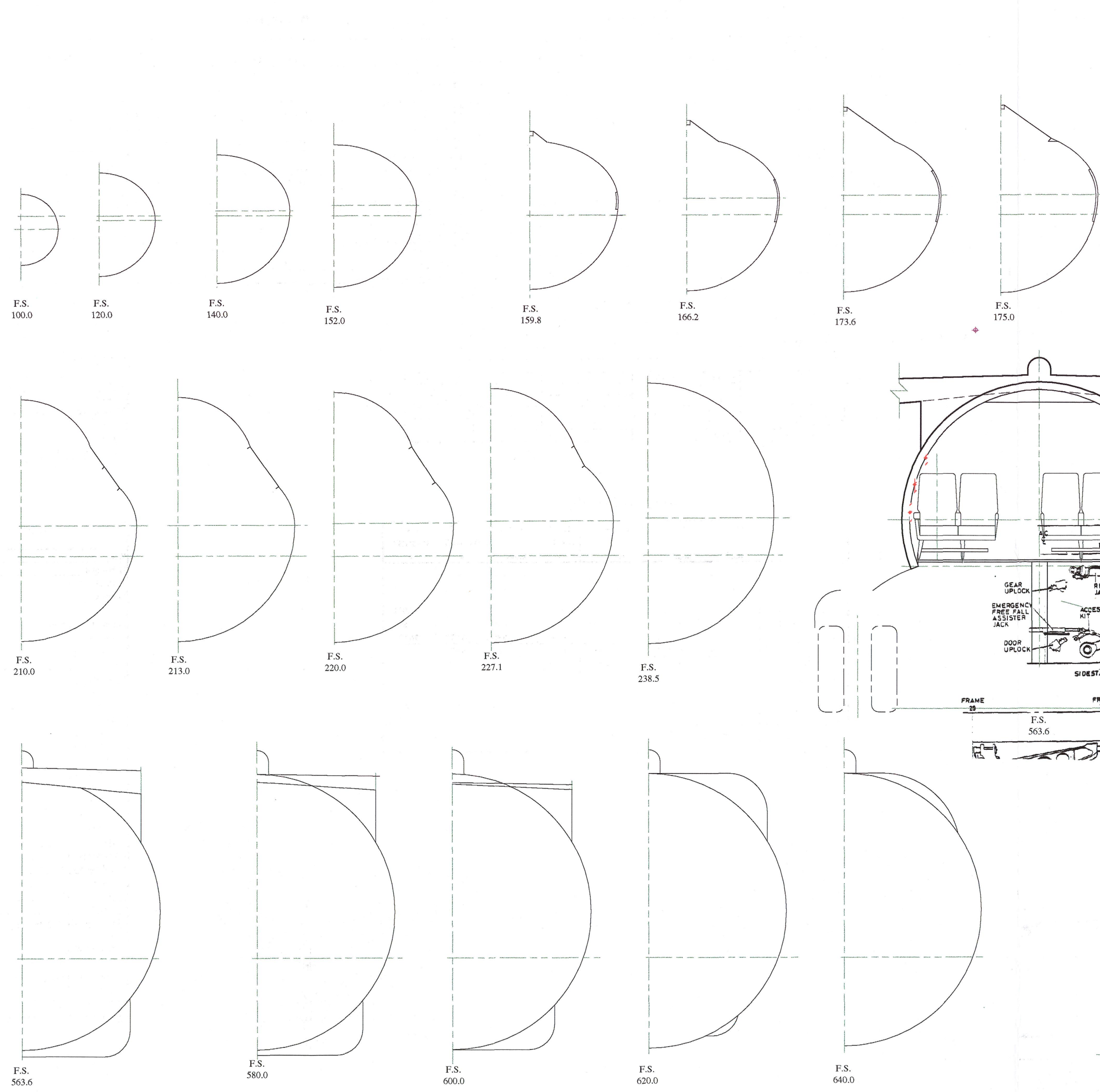
SEGMENT	DISTANCE n.mi.	TIME hours	FUEL BURN #	GLIDE RATIO -	SPEED knots	START WEIGHT #	END WEIGHT #
Takeoff	1,926 ft.	11 sec.	30	2.78	88	77,150	77,120
Climb							
Constant Speed	12	0.05	99	10.57	260	77,120	77,021
Constant Mach	20	0.07	144	12.77	300	77,021	76,877
Cruise	-	-	-	12.89	300	76,877	76,877
Transit To	468	1.56	4,940	12.89	300	76,877	71,937
Loiter or Divert	-	0.40	1,267	13.00	300	71,937	70,671
Transit From	432	1.44	4,560	12.89	300	70,671	66,111
Descent	68	0.26	1,077	10.57	260	66,111	65,034
Hold	94	0.75	3,087	12.26	213	65,034	61,947
Landing	1,926 ft.	10 sec.	1,394	2.78	71	61,947	60,553
Totals	**1,094**	**4.524**	**16,597**				
Reserve Fuel			874	or	4%		

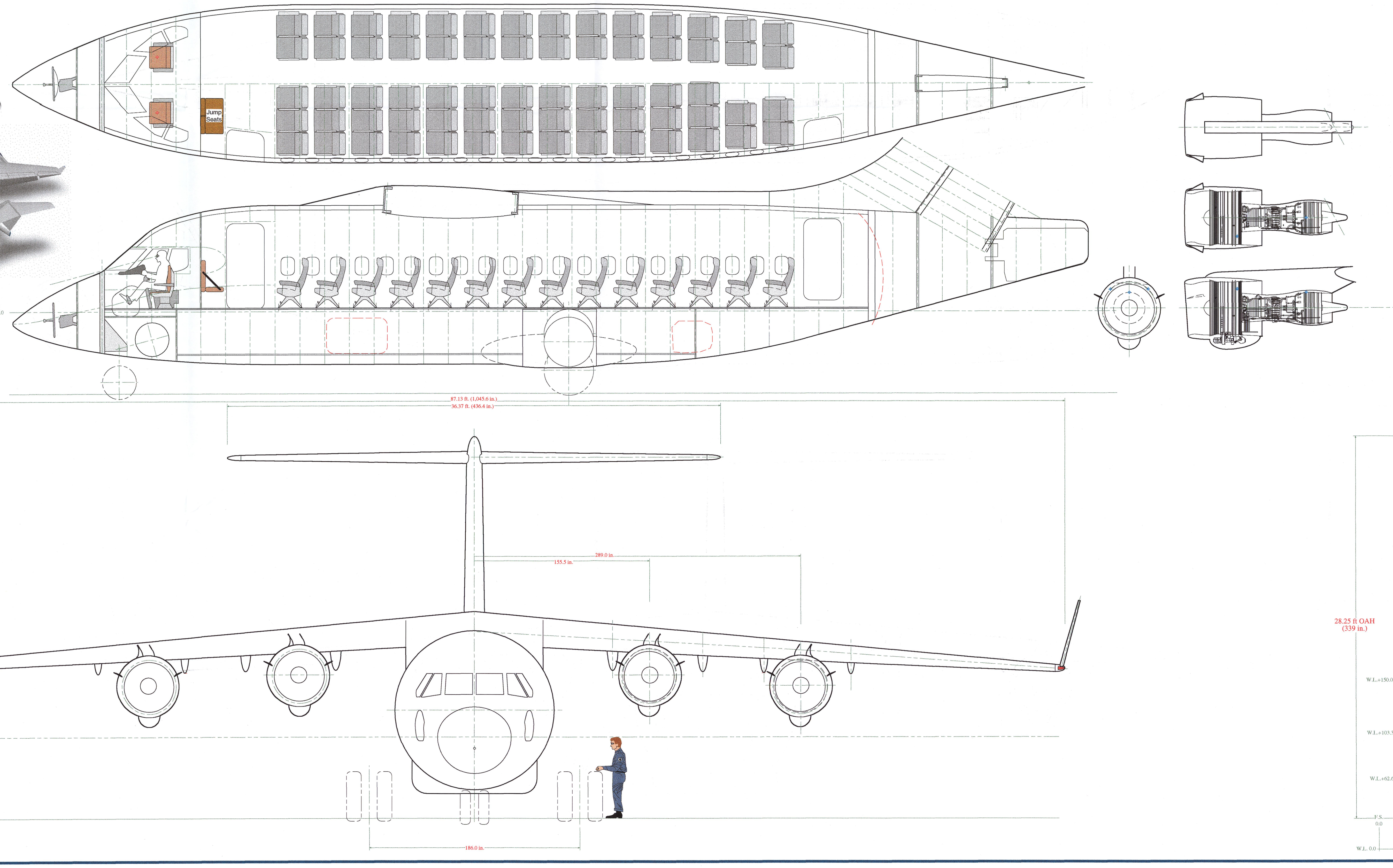
Weight & Balance

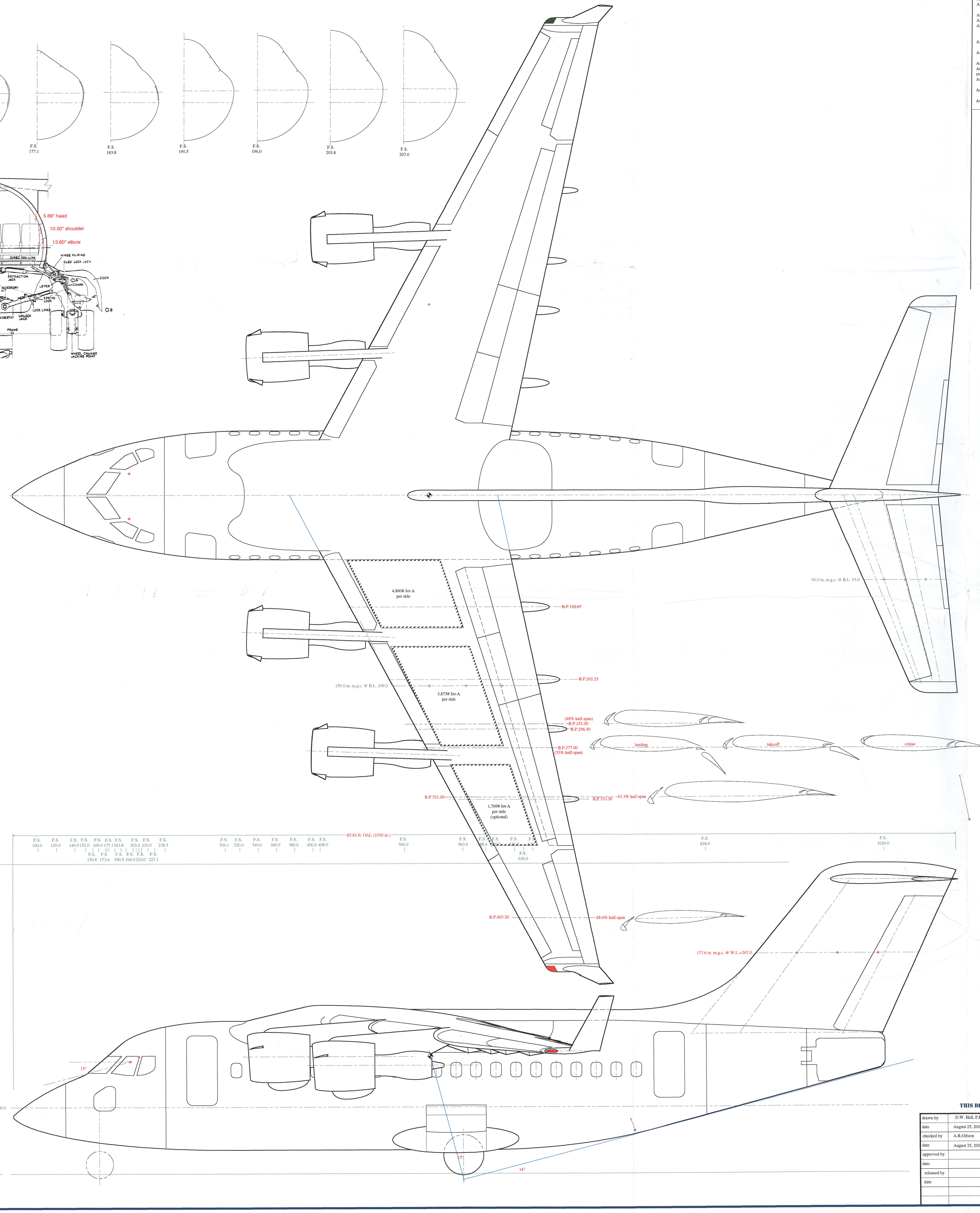
ITEM	Thorough Weights (#)	F.S. "	B.L. "	W.L. "	Wx "#	Wy "#	Wz "#
Wing	5,413	547	0	180.00	2,959,720	-	974,340
Horizontal	744	1,025	0	348.00	762,600	-	258,912
Vertical	715	950	0	267.00	679,250	-	190,905
Fuselage	14,108	520	0	140.00	7,336,160	-	1,975,120
Nacelles	1,726	422	0	151.00	727,992	-	260,626
Landing Gear (down)	2,791						
Nose	439	166	0	60.00	72,874	-	26,340
Mains	2,352	564	0	74.00	1,326,528	-	174,048
Pods	292	540	0	64.00	157,680	-	18,688
Structure	**25,789**	**543.75**	**0**	**150.41**	**14,022,804**	**-**	**3,878,979**
Surface Controls	690						
Ailerons	88	682	0	683.00	59,997	-	60,104
Flaps	333						
Inboard	167	612	0	615.00	101,963	-	102,500
Outboard	167	652	0	640.00	108,630	-	106,667
Slats	112						
Inboard #1	28	440	0	195.00	12,320	-	5,460
Inboard #2	28	503	0	183.00	14,084	-	5,124
Outboard #1	28	566	0	170.00	15,848	-	4,760
Outboard #2	28	624	0	166.00	17,472	-	4,648
Elevators	100	1,070	0	348.00	107,000	-	34,800
Rudders	57	1,030	0	260.00	58,710	-	14,820
Fixed Equipment	9,356	520	0	122.00	4,865,120	-	1,141,432
Propulsion Group	6,824	402	0	151.00	2,741,747	-	1,030,424
Empty	**42,659**	**518.66**	**0**	**149.78**	**22,125,695**	**-**	**6,389,718**
Crew	920	200	0	130.00	184,000	-	119,600
Passengers	16,100	560	0	130.00	9,016,000	-	2,093,000
Maximum Zero Fuel Weight	**59,679**	**524.90**	**0**	**144.14**	**31,325,695**	**-**	**8,602,318**
Fuel	17,471		0				
Inboard Wing	9,720	504	0	198.00	4,898,880	-	1,924,560
Mid-span Wing	7,750	550	0	188.00	4,262,500	-	1,457,000
Outboard Wing		600	0	172.00	-	-	-
Takeoff Gross	**77,150**	**524.78**	**0**	**155.33**	**40,487,075**	**-**	**11,983,878**
Max Landing Weight	**73,656**						
Quarter Chord of m.g.c. is at:		**527.28**	209	180.00			











Change Date	Changed By	Description
July 31, 2002	D.W.Hall	Add scaled C-17 wing sections and nacelle mold lines.
August 1, 2002	D.W.Hall	Revise wing/nacelle to accommodate CF34 engines. Add fuselage/wing junctions fore and aft.
August 2, 2002	D.W.Hall	Add inboard profile and line weights.
August 6, 2002	D.W.Hall	Add wing cross-sections and reposition nacelles further forward to mimic C-17 layout.
August 7, 2002	D.W.Hall	Move wing/nacelles aft 21.8 inches to get quarter m.g.c. closer to nominal c.g. location plus change weight and balance table. Take another crack at defining windscreen inall views. Define wing/fuselage junction fairings.
August 8, 2002	D.W.Hall	Finish defining aft fuselage/wing junction fairing plus attempt to define forward wing/fuselage fairing.
August 9, 2002	D.W.Hall	Redefine forward wing/fuselage junction fairing plus revise engine nacells and add pylons.
August 12, 2002	D.W.Hall	Add solid model screenshots and inboard planview.
August 13, 2002 recalculate	D.W.Hall	Revise weight statement & mission profile table + add fuel tanks to wing & weight and balance.
August 14, 2002	D.W.Hall	Add nacelle flow strakes and correct front views of nacelles plus dimensions and vertical tail torque box in inboards.
August 23, 2002	D.W.Hall	Revise weight statement and recalculate balance plus add details to nacelles and fuselage inboards.
August 25, 2002	D.W.Hall	Add flaps, slats, spoilers and flap tracks in all views plus take cross-section through main landing gear well to show retracted position.

drawn by	D.W. Hall, P.E.
date	August 25, 2002
checked by	A.R.Gibson
date	August 25, 2002
approved by	
date	
released by	
date	

NASA CAL POLY BOEING

NASA/Boeing ESTOL

70 PASSENGER REGIONAL ESTOL AIRLINER

General Arrangement Drawing

scale: 1" = 40"

PLRI-110-100-00001